Digitized by the Internet Archive
in 2010 with funding from
University of Toronto

http://www.archive.org/details/proceedings191801inst

THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1918, v. 1

JANUARY–MAY.

PUBLISHED BY THE INSTITUTION,
STOREY'S GATE, ST. JAMES'S PARK, LONDON, S.W. 1.

14 7432
13 11 18

The right of Publication and of Translation is reserved.

TJ
1
I4
1918
v.1

CONTENTS.

1918.

JANUARY–MAY.

	PAGE
List of Past-Presidents	iv
List of Officers	v
Annual Report of Council	1
PROCEEDINGS, JANUARY MEETING:—	
Nomination of Candidates for Council	43
Transferences	45
"Motor-Tractors for Tillage Purposes"; by A. Amos	47
"Traction on bad Roads or Land"; by L. A. Legros (Plates 1–40)	55
PROCEEDINGS, 71ST ANNUAL GENERAL MEETING, 15TH FEBRUARY:—	
Decease of Sir J. Wolfe Barry, K.C.B.	195
Transferences	196
Presentation of Annual Report	196
Presentation of Awards and Prizes	202
Election of Officers	203
Appointment of Auditor	205
PROCEEDINGS, MARCH MEETING:—Election of Members, &c.	207
Paper rejected by Censor	210
"Employment of Women in Munition Factories"; by Miss O. E. Monkhouse, M.B.E.	213
"Efficient Utilization of Labour in Engineering Factories"; by B. H. Morgan	239
PROCEEDINGS, MAY MEETING.—Election of Members, &c.	325
"Testing Hardness of Metals"; by C. J. B. Cooke, C.B.E.	331
"Impact Tests of Metals and new scale of Hardness"; by C. A. Edwards and F. W. Willis	335
Memoirs	371
Index to Proceedings 1918, January to May	387
PLATES 1–40.	

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)
Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)
Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)
John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)
James Kennedy, 1860. (*Deceased* 1886.)
The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)
Robert Napier, 1863–65. (*Deceased* 1876.)
John Ramsbottom, 1870–71. (*Deceased* 1897.)
Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)
Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)
John Robinson, 1878–79. (*Deceased* 1902.)
Edward A. Cowper, 1880–81. (*Deceased* 1893.)
Percy G. B. Westmacott, 1882–83. (*Deceased* 1917).
Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)
Jeremiah Head, 1885–86. (*Deceased* 1899.)
Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)
Charles Cochrane, 1889. (*Deceased* 1898.)
Joseph Tomlinson, 1890–91. (*Deceased* 1894.)
Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)
Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.
E. Windsor Richards, 1896–97.
Samuel Waite Johnson, 1898. (*Deceased* 1912.)
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900. (*Deceased* 1913.)
William H. Maw, LL.D., 1901–02.
J. Hartley Wicksteed, 1903–04.
Edward P. Martin, 1905–06. (*Deceased* 1910.)
T. Hurry Riches, 1907–08. (*Deceased* 1911.)
Sir John A. F. Aspinall, M.Eng., 1909–10.
Edward B. Ellington, 1911–12. (*Deceased* 1914.)
Sir H. Frederick Donaldson, K.C.B., 1913–14. (*Deceased* 1916.)
W. Cawthorne Unwin, LL.D., F.R.S., 1915–16.

The Institution of Mechanical Engineers.

OFFICERS.

1918.

PRESIDENT.

MICHAEL LONGRIDGE, ... London.

PAST-PRESIDENTS.

SIR JOHN A. F. ASPINALL, M.Eng., ... Manchester.
SIR ALEXANDER B. W. KENNEDY, LL.D., F.R.S., ... London.
WILLIAM H. MAW, LL.D., ... London.
E. WINDSOR RICHARDS, ... Caerleon.
W. CAWTHORNE UNWIN, LL.D., F.R.S., ... London.
J. HARTLEY WICKSTEED, ... Leeds.

VICE-PRESIDENTS.

WILLIAM H. ALLEN, ... Bedford.
SIR DUGALD CLERK, K.B.E., D.Sc., F.R.S., ... London.
HENRY DAVEY, ... Ewell.
SIR ROBERT A. HADFIELD, BART., D.Sc., D.Met., F.R.S., Sheffield.
J. ROSSITER HOYLE, ... Sheffield.
MARK H. ROBINSON, ... London.

MEMBERS OF COUNCIL.

DANIEL ADAMSON, ... Hyde.
ARCHIBALD BARR, LL.D., D.Sc., ... Glasgow.
SIR A. TREVOR DAWSON, ... London.
JOHN DEWRANCE, ... London.
SIR HENRY FOWLER, K.B.E., ... Derby.
H. S. HELE-SHAW, LL.D., D.Sc., F.R.S., ... London.
EDWARD HOPKINSON, D.Sc., ... Manchester.
GEORGE HUGHES, ... Horwich.
HENRY A. IVATT, ... Haywards Heath.
BOWMAN MALCOLM, ... Belfast.
ROBERT MATTHEWS, ... Manchester.
DONALD B. MORISON, ... Hartlepool.
SIR GERARD A. MUNTZ, BART., ... Birmingham.
ENG. VICE-ADMIRAL SIR HENRY J. ORAM, K.C.B., F.R.S., .. London.
WILLIAM H. PATCHELL, ... London.
SIR VINCENT L. RAVEN, K.B.E., ... London.
WILLIAM REAVELL, ... Ipswich.
JAMES W. RESTLER, ... London.
CAPTAIN H. RIALL SANKEY, C.B., R.E., ret., ... London.
RICHARD WILLIAMSON, ... Workington.
WILSON WORSDELL, ... Ascot.

HON. TREASURER.
F. H. NORWOOD.

AUDITOR.
RAYMOND CRANE, F.C.A.

SECRETARY.

EDGAR WORTHINGTON,

The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W. 1.
Telegraphic Address:—*Mech, Parl, London.* Telephone:—*Victoria*, 4564.

The Institution of Mechanical Engineers.

PROCEEDINGS.

ANNUAL REPORT OF THE COUNCIL
FOR THE YEAR 1917.

The Council have pleasure in presenting to the members at the Seventy-first Annual General Meeting their Report of the progress and work of the Institution during the year.

The changes which have taken place in the roll during 1917 are shown in the subjoined tabulated statement:—

	Hon. M.	M.	A.M.	A.	G.	Totals.	
Totals at 31st December 1916	7	2,723	3,031	46	440		6,247
Elected	—	61	250	3	39		
Reinstated	—	3	4	—	—		
Transferred	—	54	—	—	—		
Total additions during 1917	—	118	254	3	39	414	
Deceased	—	46	17	—	12		
Resigned	—	15	18	1	3		
Erased	—	25	64	4	11		
Graduates elected Associate Members	—	—	—	—	52		
Graduates retired under By-law 3.	—	—	—	—	32		
Elections voided	—	—		—	1		
Transferred	—	—	54	—	—		
Total deductions during 1917	—	86	153	5	111	355	
Net alterations during 1917	—	+32	+101	−2	−72		+59
Totals at 31st December 1917	7	2,755	3,132	44	368		6,306

His Majesty the King has conferred the following honours upon members :—

Baronetcy.—Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S. (*Vice-President*).

Knights Commander of the Order of the British Empire.—Mr. George J. Carter; Dr. Dugald Clerk, F.R.S. (*Vice-President*); Sir Vincent L. Raven (*Member of Council*).

Knights Bachelor.—Mr. John A. F. Aspinall, M.Eng. (*Past-President*); Mr. George T. Buckham; Mr. Vincent L. Raven; Mr. William Weir.

Commanders of the Order of the British Empire.—Mr. William Blane; Mr. Alan E. L. Chorlton; Mr. Henry Fowler; Sir G. Croydon Marks, M.P.

Companions of the Order of St. Michael and St. George.—Hon. Lieut.-Col. John D. Cormack, D.Sc.; Major Bertram Hopkinson, F.R.S.; Mr. Francis E. Kanthack; Lieut.-Col. Nathaniel Wilson, D.S.O., R.E.

Officers of the Order of the British Empire.—Mr. George Cuming; Mr. William J. Larke; Mr. Ernest Parkinson.

Companion of Honour.—Professor William Ripper, D.Eng., D.Sc.

Distinguished Service Order.—Major J. H. Dobson, S. African Pioneers; Captain N. L. Inkson, I.A.R.O.; Major B. C. L. Jervis, R.E.; Lieut.-Col. D. S. Kennedy, A.S.C.; Lieut.-Col. J. A. Methuen, K.R.R.; Major L. C. Miller, R.G.A.; Major W. H. Morgan, R.E.; Major F. G. Payne, M.G.C.; Lieut.-Col. George Rollo, Jun., K. Liverpool Regt.

Members of the Order of the British Empire.—Mr. Henry Moss; Mr. Herbert Schofield.

Military Cross.—Lieut. A. H. Atkins, R.G.A.; 2nd Lieut. C. F. Budenberg, L.D.E.; 2nd Lieut. Ian R. Cartwright, R.W.F.; Lieut. C. H. Goulden, R.E.; Lieut. H. Y. V. Jackson, R.E.; Lieut. A. R. Mangnall, R.E.; 2nd Lieut. T. S. Riley, A.S.C.; Lieut. A. J. Skinner, R.E.; Hon. Capt. R. Stevenson, A.O.D., I.O.M.; Hon. Capt. C. F. D. Suggate, A.O.D., I.O.M.; Capt. H. R. Tupper, A.S.C.; Capt. F. L. Watson, 7th W. Yorks. Regt.

Commandant Paul L. Roux has been created a Chevalier of the Legion of Honour; and Capt. John Donnelly (E.A.F.) and Lieut.-Col. H. C. Sparks, D.S.O., have received the French Military Cross.

Deceases of the following members (with dates of election) were reported during the year. The names of those who lost their lives in connexion with the War are printed in heavier type :—

1903. Arkwright, Bernard J.
1912. **ARMSTRONG, P. T., Lieut. R.N.V.R.** (*A.M.*)
1915. **BARSTOW, M. W., Lieut. R.G.A.** (*G.*)
1911. Beilken, B. J. (*Dec'd* 1916)
1887. Binnie, Sir Alexander R.
1902. Browne, Sir Benjamin C., D.C.L. (*Former Member* 1869–84)
1899. Buchanan, James.
1916. **BUCKTON, A. SCOTT, Capt. R.G.A.** (*A.M.*)
1891. Butler, James
1877. Campbell, Angus
1886. Chalmers, John R.
1893. Charlesworth, Sheard
1903. Chivers, Frank E. (*A.M.*) (*Deceased* 1916)
1903. Christiansen, Albert G.
1895. Cornish, Edwin, Eng. Capt. R.N.
1905. Craven, J. E. H. (*A.M.*)
1913. **CRICHTON, J. A., Major R.E.** (*A.M.*)
1912. **CROFTON, E. V. M., Lieut. R.E.** (*G.*)
1912. **DOUGLASS, P. C. D., Flight-Com.** (*A.M.*)
1899. Durston, Sir A. John, K.C.B., Engineer Vice-Admiral
1901. Erichsen, F. O.
1907. Ermen, B. G.
1881. Farrar, Sidney H.
1899. Ford, T. Wharton
1899. Fraser, Patrick
1907. Fyffe, A. Morton
1913. Gavin, N. A. (*A.M.*)
1913. **GRIFFITHS, R. SWIRE, Major R.G.A.** (*A.M.*)
1907 Griggs, William J.
1916. **HALL, G. S., 2nd Lieut. R.F.C.** (*G.*) (*Deceased* 1916)
1881. Hall, John Percy
1900. **HALL, W. B., Eng. Com., R.N.**
1910. **HANDCOCK R. H., Lieut. A.O.D.** (*A.M.*)
1911. **HARVEY, WILLIAM C., Lieut. K.R.R.** (*A.M.*) (*Deceased* 1916)
1870. Hawksley, Charles (*Member of Council*).
1882. Hayes, Edward
1879. Hayes, John
1885. Hill, Robert A.
1909. Hopkinson, Frank A.
1901. Jefferies, Harold S.
1890. Johnson, John W.
1903. Jones, George P.
1883. Jordan, Edward
1911. **KENNEDY, CHARLES, Lieut. R.F.A.** (*Deceased* 1916)
1892. Kennedy, Thomas
1912. Kirby, Joseph P. (*A.M.*)
1911. **LANGDON, D. E., Capt. D.C.L.I.** (*A.M.*)

1888. Latham, Baldwin
1909. Longhurst, H. A. (*A.M.*)
1887. Lorrain, James G.
1904. Luke, R. Montague (*A.M.*)
1906. Major, Charles G.
1911. **MANISTY, H. S., Lieut. R.E. M.C.** (*A.M.*)
1886. Martin, William H.
1913. **MAUNSELL, R. G. F., Capt. R.E.** (*G.*)
1875. Merryweather, J. C.
1887. Milne, William
1884. Nicholls, J. Mayne
1886. Noakes, Thomas J.
1913. **PARSONS, B. F., 2nd Lieut. R.F.C.** (*G.*)
1890. Pilkington, Herbert
1873. Radford, R. Heber
1912. **ROBB, H. B., Lieut. A.S.C.** (*G.*)
1905. Sharp, R. Gordon
1914. Shepherd, F. J. (*G.*)
1893. Shroff, A. B.
1913. Smith, James (*A.M.*)
1915. **SPINK, R. J., Serj. Can. Eng.** (*A.M.*)
1885. Spooner, George P.
1880. Stirling, James
1908. Storey, John E.
1905. Symons, Diogo A.
1906. Thomas, R. Beaumont
1914. **THORNE, GUY S., Capt. R.F.C.** (*A.M.*)
1912. Townhill, William
1913. **TREMEARNE, W. C., 2nd Lieut.** (*A.M.*) (*Deceased* 1915.)
1901. **WALKER, R. H., Lieut.** (*A.M.*)
1911. Watson, Cecil
1862. Westmacott, Percy G. B. (*Past-President*)
1911. **WORSSAM, LESLIE H., Private H.A.C.** (*A.M.*)

Of these, Mr. Westmacott became a Member of Council in 1869, a Vice-President in 1876, and occupied the Presidential Chair in 1882–83. Mr. Hawksley served as a Member of Council from 1913.

The Accounts for the year ended 31st December 1917 are submitted (*see* pages 14 to 22), having been duly certified by the Auditor. The total revenue was £22,865 12*s.* 9*d.*, while the expenditure was £22,701 1*s.* 7*d.* (including £9,943 2*s.* 2*d.* invested for Reserve Funds), leaving a balance of revenue over expenditure of £164 11*s.* 2*d.*

The former "Sinking Fund for the Redemption of Debentures and the Institution's Leasehold Property" has been superseded by four separate Reserve Funds, namely, the Debenture Redemption Sinking Fund, the Leaseholds Amortisation Sinking Fund, the Staff Pensions Fund, and the General Reserve Fund (*see* pages 18–19). The various securities have been entered at their market

value as on 18th May 1917, the date when the new Funds were instituted by the Council.

The total assets of the Institution amount to £144,319 3*s.* 8*d.* Deducting therefrom the £34,025 of Debentures, £5,000, the balance of Messrs. R. and R. H. Williamson's loan, other small liabilities, and £37,049 15*s.* 1*d.*, the sum of the four Reserve Funds, there remains a net credit balance of £66,503 9*s.* 2*d.*

The certificates of all securities have been duly verified by the Finance Committee and the Auditor.

The Institution House being still occupied by H.M. Government, the General Meetings have been held in the Theatre of The Institution of Civil Engineers, for the use of which as well as the reading room and library the Council again desire to record their indebtedness and tender their hearty thanks.

The names of over one thousand members have now been received as being, or having been, on Active Service, many from the commencement of the War; and the Council regret that during the past year twenty-two have lost their lives in various parts of the world. Nine members of the Institution Staff have now joined the Forces, one of whom has died from wounds.

With a view to helping those still on active service, and other members engaged on war work, to find suitable employment on their return to civil life, the Council have prepared and issued to them, so far as their addresses are known, forms whereon they may record such particulars of their training and experience as will enable the Secretary to answer inquiries likely to bring together those offering and those seeking positions in engineering works or offices. So far about a hundred of these have been filled in and returned, and are now being analysed and tabulated for future use. It is almost unnecessary, though perhaps better, to add that all information given in this way will be treated as confidential, and will only be used for the benefit of the giver.

The Thomas Hawksley Gold Medal for 1918, given annually for the best Paper published in the Proceedings of the preceding year, has been awarded to Mr. A. A. Griffith, M.Eng., and Mr. G. I. Taylor, M.A., for their Paper on "The use of Soap Films in solving Torsion Problems" (Proceedings 1917, page 755).

Grants were made by the Council, for the year, in aid of the four Researches now being carried on under the direction of the Institution, namely:—

Alloys	£250
Steam-Nozzles	£100
Hardness Tests	£100
Wire Ropes	£450

The following paragraphs describe briefly the work done by these various Research Committees:—

Alloys Research.—The Committee has been occupied with investigations on various light ternary alloys. These have been conducted at the National Physical Laboratory with the assistance of the Department of Scientific and Industrial Research from whom the Committee received a grant of £400 in addition to a sum of £800 paid directly to the Laboratory for the provision of special plant. The Committee's eleventh Report which would have contained the result of these investigations has been temporarily withheld in the public interest.

Steam-Nozzles.—The Committee has been so fully occupied on War work that it has been impossible to construct apparatus and to carry out tests; but complete detailed working drawings of the apparatus for measuring the impulse of steam-jets have been prepared, and it is hoped that this apparatus may shortly be put in hand, and such progress made as present circumstances permit.

Hardness Tests.—Dr. Stanton, with his special machine at the National Physical Laboratory, has continued the series of tests for the Committee with special reference to the effects of variations of load and speed on rate of wear. A series of wear rings has been made of varying widths, from material supplied by Sir Robert

Hadfield, who has also undertaken their hardening. Another holder for these rings has been constructed of a form which will considerably facilitate regrinding. A series of specimens have been prepared and the tests are now in hand. The work has been delayed for a few months owing to some of the apparatus being required for urgent War work. In addition to the Institution's grant, a sum of £100 has been received from the Department of Scientific and Industrial Research.

Arising out of the discussion on the Report of the Hardness Tests Research Committee (Proceedings 1916, page 677), Sir Robert A. Hadfield, Bart., Vice-President, placed in the hands of the Institution a sum of £200 to be awarded, under Conditions set out on page 26, as a Prize or Prizes for the description of a new and accurate method of determining the hardness of metals, especially metals of a high degree of hardness. The Council regret that as yet few such descriptions have been received.

Wire Ropes.—The work of the Committee has been again much delayed by preoccupation of its members with War work, also by the prolonged illness of the Chairman. Nevertheless a design for a testing machine has been approved in principle, for giving a somewhat wider range of tests, in the direction of providing for more bends, both simple and reverse, than originally contemplated, also for bends in planes at right angles. The choice of a site for its erection has been deferred, as the research is not considered necessary for the prosecution of the War.

In response to the announcements, in the Institution Journal for December 1916 and January 1917, of the offer from Mr. Richard Williamson of a gift of £500 in aid of engineering research, and to the invitation to Members of the Institution to suggest suitable subjects for such research, a number of suggestions were received. The Council, acting on behalf of Mr. Richard Williamson and his brother, have selected the following as being suitable: A Research to determine the best form and material for Piston and Piston-Rings, especially for Internal-Combustion Engines; and now await the approval of the Department of Scientific and Industrial

Research, through whom Mr. Williamson's offer was transmitted to the Institution.

An offer of £500 from Mr. T. Bernard Hall has been gratefully accepted to found a Prize Fund for Papers submitted to the Institution, dealing with invention, design, or research in Mechanical Engineering. The special Regulations for this Award are printed on page 27.

A grant of £50 was made in March towards the work of the recently constituted Conjoint Board of Scientific Societies, and representatives of the Institution have given evidence before the Board on the subject of engineering education.

A representative Meeting of Engineers and others interested in the professional Training of Engineers was held at the Institution of Civil Engineers in October, when a resolution was passed expressing the opinion that some form of central organization was necessary for the purpose of co-ordinating the scholastic with the workshop and office training of engineers. A Committee representative of the principal Engineering and Educational Bodies was appointed to give effect to this resolution.

During the year the Council received information that offers were being made in Australia on behalf of American Engineering firms to take and train apprentices on very advantageous terms, including a liberal living wage during the period of apprenticeship. These offers have received the attention of the Council as likely to have far-reaching consequences, but no formal action has been taken because the Council found that the B.E.A. (the British Engineers Association), a representative body of manufacturing engineers, was dealing with the matter, and it was thought that this body could deal with it more effectively than the Institution. The matter was brought to the notice of the Members in the January Journal, 1918, but it is mentioned here again on account of its interest and importance.

The Institution Examinations were held in October. 13 Candidates passed the Graduateship and 15 the Associate Membership Examination. On the results of the Associate Membership Examination, a Prize of the value of £5 was awarded to C. T. Glass-Hooper, while J. K. Greening (*G.*) and R. Hedley (*G.*) received Honourable Mention. A Prize of the value of £3 was also awarded to A. L. Williams, on the results of the Graduateship Examination. The next Examinations will be held in October 1918.

The Advisory Committees for India and South Africa which were constituted in 1916 have continued to act during the year, and the Council desire to acknowledge with grateful thanks the assistance thus rendered. A similar Committee is being constituted in Australia.

Monthly General Meetings were held throughout the year, with the exception of June, July, August, and September. These Meetings were occupied with the reading and discussion of the following Papers:—

The Manufacture of Gauges at the L.C.C. Paddington Technical Institute; by A. G. Cooke, M.A., W. J. Gow, A.R.C.S., and W. G. Tunnicliffe, *Associate Member.*

Alternating Stress Experiments; by William Mason, D.Sc., *Associate Member.*

Heat Treatment of Large Forgings; by Sir William Beardmore, Bart., *Member.*

Heat Treatment of Steel Forgings; by H. H. Ashdown.

Address by the President, Michael Longridge.

Notes on the Construction of Turbine-Pumps; by Alan E. L. Chorlton, *Member.*

A Comparison of the Working Costs of the principal Prime Movers; by Oswald Wans, *Member.*

Some Notes on Air-Lift Pumping; by A. W. Purchas, *Associate Member.*

The use of Soap Films in solving Torsion Problems; by A. A. Griffith, M.Eng., and G. I. Taylor, M.A.

The following Papers were accepted for publication in the Proceedings, with discussion in writing:—

An Energy-Diagram for Gas Mixture, and Some of its Uses; by William Alexander, *Associate Member.*

The Removal of Iron Discoloration and Objectionable Odour from a Public Water Supply, without the use of Chemicals; by A. E. Adams, *Associate Member*.

The following Papers were selected for publication in an abridged form in the Proceedings:—

Fire Prevention and Extinction; by Bernard A. Westbrook.
Automatic and Semi-Automatic Machine-Tools; by C. Warren Boulton.
The Manufacture of Oxygen and its Use for Welding and Metal-Cutting; by J. M. Christie, *Member*.

Captain H. Riall Sankey, C.B., R.E., *Member of Council*, delivered the fifth "Thomas Hawksley" Lecture, on "Heat Engines" (Proceedings 1917, page 701), in London on 30th November. The Lecture was repeated by Captain Sankey in Birmingham and Manchester.

The thanks of the Institution have been expressed to the following gentlemen who kindly acted as Honorary Local Correspondents, to make arrangements for Local Meetings, during the Session 1916–17:—

Mr. R. A. Copperthwaite, *Member* (Newcastle).
*Professor A. B. Field, *Member* (Manchester).
Mr. Frederick Grover, *Member* (Leeds).
Mr. John W. Hall, *Member* (Birmingham).
Mr. Hugh Reid, *Member* (Glasgow).
Professor W. Ripper, C.H., D.Eng., D.Sc., *Member* (Sheffield).
Mr. David E. Roberts, *Member* (Cardiff).

Three Local Meetings were held in Birmingham and Manchester and one in Leeds, for the further discussion of Papers presented in London and for the repetition of the "Thomas Hawksley" Lecture. Invitations were extended to the Members of the Local Engineering and Metallurgical Societies to attend and take part in these Meetings.

---

* Professor Field having since left Manchester, Mr. Dempster Smith was appointed to act as Honorary Local Correspondent.

Owing to the war conditions, the Committee of the Calcutta and District Section decided to suspend the Meetings during the Session 1916–17. The Council have been in correspondence during the year with members in India, and are considering the best means of enlarging the corporate life of its members in India and other distant parts of the British Empire. The Institution contributed £25 towards the expenses of the Section in 1917.

The Graduates' Meetings were again suspended during the year, but facilities have been kindly afforded by which Graduates have been enabled to attend the Sessional Meetings of the Engineering Societies of the Universities of Bristol, Edinburgh, Glasgow, Manchester, and Armstrong College, Newcastle-on-Tyne.

The Council desire to thank the members and others who have made presentations to the Library. A complete list of additions will be found on pages 28–41. Although access to the Library has not been possible since the Institution premises were taken over by the Ministry of Munitions, every endeavour has been made to meet the requirements of members, both by loan and search from the limited number of modern works which are available.

The Institution has been represented on the—

Courts of the Universities of Bristol, Liverpool, and Sheffield.
Governing Board of the Imperial College of Science and Technology.
General Committee of the Royal Society for administering the Government Grant for Scientific Investigations.
National Physical Laboratory.
Engineering Committee of the Government Department of Research.
Engineering Standards Main Committee and Sectional Committees.
School of Metalliferous Mining (Cornwall).
London Committee of the University of Hong Kong.

(Conjoint) Board of Scientific Societies, organized by the Royal Society.

Technical Committee of The Institution of Automobile Engineers and The Society of Motor Manufacturers and Traders.

Corrosion Committee of The Institute of Metals.

Conference at the Board of Education to consider a scheme for recording the educational work of interned British Prisoners.

Committee to consider the question of the need of some special training for Road Engineers.

Nomenclature Committee, constituted by The Institute of Metals.

(In suspense during the War.)

Executive Committee of the Engineering Institutions' Volunteer Engineer Corps.

Grand Committee of the City of Westminster Volunteers.

Steel Research Committee of the Institution of Automobile Engineers and Society of Motor Manufacturers and Traders.

The question of the Compulsory Adoption of the Metric System has been prominently brought to the notice of the engineering profession during the year. At the request of the Committee on Commercial and Industrial Policy, of which Lord Balfour of Burleigh is Chairman, the Council of the Institution appointed the following four Members of the Council to give evidence before them:—Dr. William H. Maw *Past-President*; Mr. William H. Allen (*Vice-President*); Sir Robert A. Hadfield, Bart., F.R.S. (*Vice-President*); and Sir Vincent L. Raven, K.B.E. (*Member of Council*).

From time to time technical literature has been supplied by the Council and Members of the Institution to the Board of Education for transmission to British Prisoners of War, and in the early part of the year a Conference was held at the Board of Education, at

which the Institution was represented by Dr. Unwin, when a resolution was passed expressing approval of a scheme to enable the holding of examinations in civilian internment camps in enemy countries.

Benevolent Fund.

The Benevolent Fund have made grants to several members and dependents of members of the Institution. 98 Life Members have made donations of Ten Guineas and upward, and 204 Ordinary Members are Annual Subscribers of not less than Half a Guinea. It is to be much regretted that a large number of members of the Institution have not yet subscribed.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£ s. d.	£ s. d.
To Expenses of Maintenance and Management—		
Salaries and Wages	4,461 11 0	
Postages, Telegrams, and Telephone	657 1 7	
Heating, Lighting, and Power	47 16 8	
Fittings and Repairs	8 0 6	
Housekeeping	64 6 8	
Incidental Expenses	42 6 4	
		5,281 2 9
,, Printing, Stationery, and Binding—		
Printing and Engraving Journal	1,736 4 0	
Stationery and General Printing	697 3 9	
Binding	105 13 11	
		2,539 1 8
,, Rent, Rates, Taxes, &c.—		
Ground Rent (Birdcage Walk)	1,107 17 2	
Do. No. 5 Princes Street	135 0 0	
Rent of temporary Offices	650 0 0	
Warehouse Rent	18 0 0	
Insurance	5 10 4	
	1,916 7 6	
Less Warehouse Rent refunded by Government	36 0 0	
		1,880 7 6
,, Meeting Expenses—		
Printing	154 13 2	
Travelling and Incidental Expenses	89 0 1	
Reporting	36 12 1	
Local Meetings	28 11 5	
		308 16 9
,, Calcutta and District Section		25 0 0
,, Books purchased		29 10 9
,, Law Charges		4 4 0
,, Examinations		120 1 0
,, Researches		787 3 3
,, Donation to Board of Scientific Societies		50 0 0
,, Depreciation on Furniture and Fittings		161 17 9
,, Debenture Interest		1,361 0 0
,, Interest on Loan		209 14 0
,, Debenture Redemption Sinking Fund		1,841 19 9
,, Leaseholds Amortisation Sinking Fund		7,367 19 1
,, General Reserve Fund		733 3 4
Total Expenditure		22,701 1 7
Balance, being excess of Revenue over Expenditure (exclusive of value of Subscriptions in arrear), carried to Balance Sheet		164 11 2
		£22,865 12 9

FOR THE YEAR ENDED 31ST DECEMBER 1917. *Cr.*

Revenue.

	£	s.	d.
By Subscriptions for 1917	14,372	0	0
„ Subscriptions in arrear, paid in 1917	1,231	0	0
„ Rents of Institution Building (including Furniture from June 1915)	6,280	6	10
„ Bank Deposit Interest	92	13	7
„ Sale of Proceedings, Journals, and Bound Volumes— *Extra Copies sold*	373	17	9
„ Examination Fees	49	7	0
„ Debenture Transfer Fee	0	2	6
„ Grants for Research— *From the Government*	466	5	1
	£22,865	12	9

Dr. BALANCE SHEET

	£ s. d.	£ s. d.
To 4% Debentures (1912 Issue):—		
327 *Debentures of* £100 *each*	32,700 0 0	
23 *Debentures of* £50 *each*	1,150 0 0	
7 *Debentures of* £25 *each*	175 0 0	
		34,025 0 0
,, Sundry Creditors—		
Loan from Messrs. Richard and Robert H. Williamson	5,000 0 0	
Accounts owing at 31*st Dec.* 1917 . . .	1,367 2 0	
Unclaimed Debenture Interest (coupons not presented)	185 7 5	
		6,552 9 5
,, Subscriptions paid in advance		188 10 0
,, Reserve Funds (see pages 18–19) *per contra*—		
Debenture Redemption Sinking Fund . .	5,221 13 0	
Leaseholds Amortisation ,, ,, . .	20,835 7 1	
Staff Pensions Fund	430 13 3	
General Reserve Fund	10,562 1 9	
		37,049 15 1
,, Balance, being Capital of the Institution, exclusive of the Reserve Funds:—		
Balance at 31*st Dec.* 1916	75,691 12 6	
Deduct— £ s. d.		
Amount set aside for re-constitution of the four Reserve Funds . . . 6,102 4 2		
Cost of writing down Securities to market value at 18*th May* 1917 3,778 10 4		
	9,880 14 6	
	65,810 18 0	
Add—		
Excess of Revenue over Expenditure for the year ended 31*st Dec.* 1917 .	164 11 2	
Amount received from Entrance Fees during 1917	428 0 0	
Amount received from Life Compositions during 1917	100 0 0	
		66,503 9 2
		144,319 3 8
,, Trust Funds (see pages 20–22), *per contra*		4,812 17 7
		£149,132 1 3

Signed by the following Members of the Finance Committee:—

MARK ROBINSON (*Chairman*). W. H. MAW.
MICHAEL LONGRIDGE. H. S. HELE-SHAW.

AT 31ST DECEMBER 1917.

Cr.

	£	s.	d.	£	s.	d.
By Cash (exclusive of Reserve and Trust Funds)—						
In Union of London and Smiths Bank—						
Deposited at Interest	2,500	0	0			
On Current Account	925	16	2			
	3,425	16	2			
In the Secretary's hands	68	7	1			
				3,494	3	3
,, Amount in Union of London and Smiths Bank to meet unclaimed Debenture Interest (*coupons not presented*)				185	7	5
,, Reserve Funds, Investments and Cash in Bank for investment (see pages 18-19), *per contra*				37,049	15	1
,, Subscriptions in arrear, *not valued.*						
,, Furniture and Fittings (*less depreciation*)				1,456	9	4
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)				1,340	0	0
,, Proceedings—stock of back numbers, *not valued.*						
	£	s.	d.			
,, Institution House *Cost*	60,270	2	10			
,, Princes Street Extension ,,	40,523	5	9			
				100,793	8	7
				144,319	3	8
,, Trust Funds, Investments and Cash in Bank (see pages 20–22), *per contra*—	£	s.	d.			
Willans Premium Fund	174	15	8			
Water Arbitration Prize Fund	521	11	9			
Starley Premium Fund	452	9	4			
Bryan Donkin Fund	381	16	6			
Thomas Hawksley Fund	2,563	16	2			
Sir R. Hadfield Prize Fund	205	18	2			
T. Bernard Hall Prize Fund	512	10	0			
				4,812	17	7
				£149,132	1	3

I have examined the above Balance Sheet and report that I have obtained all the information and explanations I have required. In my opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of the information and explanations given to me and as shown by the Books of the Institution.

RAYMOND CRANE, F.C.A.,
Auditor,
46/47 London Wall, London, E.C.

15th January 1918.

DEBENTURE REDEMPTION SINKING FUND.

(*Constituted on 18th May* 1917.)

	£	s.	d.	£	s.	d.
Investment £5,000 5% War Stock 1929-1947 . *cost*	4,746	12	8			
Do. £253 7*s.* 4*d.* 5% National War Bonds 1927 . . *cost*	253	7	4			
				5,000	0	0
By Cash—Interest received in 1917				221	13	0
Total, as per Balance Sheet				£5,221	13	0

LEASEHOLDS AMORTISATION SINKING FUND.

(*Constituted on 18th May* 1917.)

	£	s.	d.	£	s.	d.
Investment £20,000 5% War Stock 1929-1947 *cost*	18,986	10	8			
Do. £1,013 9*s.* 4*d.* 5% National War Bonds 1927 . . *cost*	1,013	9	4			
				20,000	0	0
By Cash—Interest received in 1917				835	7	1
Total, as per Balance Sheet				£20,835	7	1

STAFF PENSIONS FUND.

	£	s.	d.
Investment £700 L. & S. W. Rly. 3% Consolidated Deb. Stock.			
Market Value at 18th May 1917	420	0	0
By Cash—Interest received in 1917 . . . £ 7 17 6			
,, ,, Income Tax refunded in 1917 . . . 2 15 9			
	10	13	3
Total, as per Balance Sheet	£430	13	3

GENERAL RESERVE FUND.

	£	s.	d.
Investments—			
£5,408 0 0 L. & N. W. Ry. 3% Debenture Stock.			
5,080 12 0 Midland Ry. 2½% Debenture Stock.			
3,084 10 8 Metropolitan Water (B) 3% Stock.			
1,586 0 0 London County 3½% Consolidated Stock.			
670 0 0 L. & S. W. Ry. 3% Consolidated Deb. Stock.			
Market Value at 18th May 1917	9,283	18	2
Investment £733 3s. 4*d*. 5% National War Bonds 1927 . *cost*	733	3	4
	10,020	1	6
By Cash—Interest received in 1917 . . . £ 357 6 4			
,, ,, Income Tax refunded in 1917 . . . 184 13 11			
	542	0	3
Total, as per Balance Sheet . . .	£10,562	1	9

WILLANS PREMIUM FUND.

(*Subscribed*, 1897, *by friends of the late P. W. Willans, to commemorate the services he rendered to Engineering and Electrical Science.*)
(Under a Joint Trust with The Institution of Electrical Engineers.)

	£	s.	d.	£	s.	d.
Investment £159 8s. 5d. of India 3% Stock . . . . . *cost*				165	5	0
By Cash Balance from 1916	4	15	4			
,, Interest received in 1917	4	15	4			
				9	10	8
Total, as per Balance Sheet				£174	15	8

(For Declaration of Trust, *see* page 23.)

WATER ARBITRATION PRIZE FUND.

(*Presented by Sir Edward Fry and the Metropolitan Water Board, to commemorate the holding, in the Institution building, of the Court of Arbitration*, 1903–5, *relating to the purchase of the Undertakings of the eight London Water Companies.*)

	£	s.	d.	£	s.	d.
Investment £523 10s. 2d. of Metropolitan Water (B) 3% Stock *cost*				500	0	0
By Cash Balance from 1916	37	8	10			
,, Interest received in 1917	11	15	6			
,, Income Tax refunded in 1917	3	15	5			
	52	19	9			
To Award to Mr. Walter Clemence	31	8	0			
				21	11	9
Total, as per Balance Sheet				£521	11	9

(For Regulations, *see* page 24.)

STARLEY PREMIUM FUND.

(*Presented*, 1906, *by the J. K. Starley Memorial Committee.*)

	£	s.	d.	£	s.	d.
Investment £435 8s. 5d. of London County 3½% Consolidated Stock . . . . . *cost*				440	7	6
By Cash Balance from 1916	40	3	3			
,, Interest received in 1917	11	7	4			
,, Income Tax refunded in 1917	3	11	3			
	55	1	10			
To Award to Mr. R. E. Phillips	43	0	0			
				12	1	10
Total, as per Balance Sheet				£452	9	4

(For Declaration of Trust, *see* Proceedings 1916, page 25.)

BRYAN DONKIN FUND.

(*Bequest*, 1909, *under the Will of the late Bryan Donkin, Vice-President* 1901–2.)

	£	s.	d.	£	s.	d.
Investment £349 15*s.* 8*d.* of London County 3½% Consolidated Stock . . . . . *cost*				360	6	6
By Cash Balance from 1916	9	10	2			
„ Interest received in 1917	9	2	8			
„ Income Tax refunded in 1917	2	17	2			
				21	10	0
Total, as per Balance Sheet				£381	16	6

(For Regulations, *see* page 25.)

THOMAS HAWKSLEY FUND.

(*Established by the late Charles Hawksley, Member of Council* 1913–1917, *to commemorate the Centenary on* 12*th July* 1907 *of the birth of his Father, the late Mr. Thomas Hawksley, F.R.S., President* 1876–1877 (*died* 23 *Sept.* 1893).)

	£	s.	d.	£	s.	d.
Capital—						
£1,300 *Southend Waterworks Co.* 4% *Perpetual Debenture Stock . . . . nominal value*	1,300	0	0			
£700 *Lowestoft Water and Gas Co.* 4% *Debenture Stock . . . . . nominal value*	700	0	0			
Accumulated Interest (invested)—						
£420 *G. W. Ry.* 4½% *Debenture Stock . cost*	499	14	6			
				2,499	14	6
By Cash Balance from 1916	61	18	4			
„ Interest received in 1917	74	3	6			
„ Income Tax refunded in 1917	22	4	0			
	158	5	10			
To Lecturer, 1917 . . . . . £ 52 10 0						
„ Expenses of London and Provincial Meetings 31 14 2						
„ Premium, Mr. R. W. Fenning . 10 0 0						
	94	4	2	64	1	8
Total, as per Balance Sheet				£2,563	16	2

(For Declaration of Trust, *see* Proceedings 1915, page 25.)

SIR ROBERT HADFIELD PRIZE FUND.

(*Presented*, 1917, *by Sir Robert A. Hadfield, Bart., D.Sc., D.Met., F.R.S., Vice-President, to provide* (1917–1921 *inclusive*) *a prize or prizes for the description of a new and accurate method of determining the hardness of Metals.*)

	£	s.	d.	£	s.	d.
Investment £200 5% War Stock 1929–1949 (*Bonds*) . . *cost*				190	0	0
By Cash Balance	10	0	0			
,, Interest received in 1917	5	18	2			
				15	18	2
Total, as per Balance Sheet				£205	18	2

(For Conditions, *see* page 26.)

T. BERNARD HALL PRIZE FUND.

(*Presented*, 1917, *by Mr. T. Bernard Hall, Member, for the provision of prizes for original communications dealing with invention, design, or research in Mechanical Engineering, presented to the Institution.*)

	£	s.	d.
Investment, £500 5% War Stock 1929–1949 (*transferable by Deed*) *nominal value*	500	0	0
By Interest received in 1917	12	10	0
Total, as per Balance Sheet	£512	10	0

(For Conditions, *see* page 27.)

WILLANS PREMIUM FUND.

Eighth Award to be made by the Institution of Mechanical Engineers in February 1919.

Declaration of Trust.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical Science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorized to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by The Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original Paper communicated to their Institution, dealing with such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a Paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In the case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

Water Arbitration Prize.

Regulations for the Sixth Award, to be made in February 1919.

1. The Award will be made for the best original Paper dealing with any of the following subjects:—Methods of Purification of Water for Domestic or Trade Purposes, or Description of Hydraulic Machinery, or New Investigations in Hydraulics, or New Developments in Distribution of Water for Town's Supply or Irrigation, or Advances in the Utilization of Water Power, accepted by the Council for publication with or without discussion in the Institution Proceedings of 1917 and 1918, provided that the Paper be of sufficient merit in the judgment of the Council.

2. Papers should be sent in as soon as possible, but not later than 1st April 1918.

3. Papers should be illustrated by scale drawings, but may be accompanied by photographs, lantern-slides, and specimens.

4. Any Paper not accepted for printing in the Proceedings will be returned to the Author.

5. The Prize will have the value of about £30, and will be accompanied by a Certificate bearing the Seal of the Institution.

Bryan Donkin Fund.

Regulations for the Fourth Award, to be made in February 1919.

1. The Bryan Donkin Award, consisting of the interest on the sum of £360 6*s.* 6*d.*, shall be made triennially (beginning in February 1910) by the Council, as a grant or grants in aid of original research in Mechanical Engineering.

2. Applications for grants must be received at the Institution on or before 31st October in the year immediately preceding the year of the next Award. Each application must be accompanied by the names and addresses of two references as to the ability of the applicant to undertake the proposed research, and must contain a concise statement as to the nature of the research and the sum applied for, with details of the proposed expenditure.

3. All applications received in accordance with Clause 2 shall be considered by the Council, on a Report from the Research Committee. The Council shall decide as to the allocation of the sum available, and if it is considered that none of the applicants is deserving of a grant, or if the grants made amount to less than the sum available, the surplus shall be devoted to aiding any of the Researches of the Institution, and shall be distributed in such proportions as the Council shall decide.

4. The full amount of each grant made by the Council shall be handed over to the applicant at his request. If no request for payment is received within six months the grant shall lapse.

5. Any portion of a grant not expended by 31st December in each year shall be forthwith returned to the Institution, unless permission in writing has been previously received from the Institution for its retention, in order to continue the research.

6. The recipient of a grant shall send to the Institution on each 1st January during the continuation of his research a Report of his progress, with particulars of the expenditure incurred, accompanied as far as possible by vouchers. He shall also, at the request of the Council, send to the Institution a statement of his experiments and the results obtained; and the Council shall be at liberty to publish the same in the Proceedings of the Institution.

7. Any recipient of a grant who fails to fulfil the conditions in Clause 6, or whose Report is not considered satisfactory by the Council, may be required to return to the Institution the whole amount granted to him.

Sir Robert Hadfield Prize.

For a new Method of determining the Hardness of Metals.

First Award in January 1918.

Conditions of Award.

1. Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S., placed in January 1917, in the hands of the Institution of Mechanical Engineers the sum of £200, which with any income therefrom may be awarded at the discretion of the Council of the Institution as a Prize or as Prizes, for the description of a new and accurate method of determining the hardness of metals, especially of metals of a high degree of hardness.

2. The ordinary tests of hardness, such as are described in the Report of the Hardness Tests Research Committee (Proceedings of the Institution of Mechanical Engineers, 1916, pages 677 to 778), which should be consulted by competitors, fail to some extent when the hardness of the material exceeds about 600 to 800 Brinell. What is desired is the description of a research for or an investigation of some method of accurately determining hardness, suitable for application in metallurgical work in cases in which present methods partially fail.

3. The Award or Awards will be made by the Council of the Institution of Mechanical Engineers, whose decision will be in all cases final.

4. The Council will consider annually all communications received, and may then award a Prize or Prizes. But in January 1922 the offer of Prizes will be withdrawn, and any unexpended balance of the Prize Fund will be diverted to any other purposes to be determined at the discretion of the Council.

5. The Council may award the whole or any part of the sum available at any time if a communication is received which, in their opinion, is of sufficient originality and importance and satisfies the object aimed at; or they may from time to time award portions of the Fund, not exceeding in all £75 in any one year, for communications which do not completely solve the problem, but which appear to advance the knowledge of methods of testing hardness. The Institution will probably be willing and reserve the right to publish in its Journal any communications for which a prize is awarded.

6. A communication should be accompanied by scale drawing of any new apparatus described, or by a model or an example of the apparatus itself. If the communication describes a new invention, likely to be of commercial value, it is desirable that provisional protection should have been obtained before it is submitted for consideration.

7. Communications should be addressed to The Secretary, The Institution of Mechanical Engineers 11 Great George Street, Westminster London S.W., 1, and marked "Method of determining Hardness," and should reach him at least one month before the 1st January in any year.

T. Bernard Hall Prizes.

First Award to be made in February 1920.

Conditions of Award.

A sum of Five Hundred Pounds having been offered by Mr. T. Bernard Hall (Member) for the provision of prizes for original Communications dealing with invention, design or research in Mechanical Engineering presented to the Institution, the Council hereby give notice :—

1. A medal prize or prizes of an aggregate value not exceeding two years' net income of the Trust Fund may be awarded every second year to the Author or Authors of any original Communication

or Communications dealing with invention, design, or research in Mechanical Engineering, published in the Proceedings of the Institution during the preceding two years, and which in the opinion of the Council shall be of sufficient merit.

2. The award or awards will be made by the Council of the Institution of Mechanical Engineers, whose decisions will be final in all cases.

3. Should the value of the awards made at the end of any biennial period be less than the income for the period, the balance may be added to the capital of the Fund or may be used for assisting researches at the discretion of the Council.

LIST OF ADDITIONS TO THE LIBRARY.

BOOKS, *see p.* 28.
OFFICIAL PUBLICATIONS, *see p.* 29.
PAMPHLETS, *see p.* 32.
DIRECTORIES, ANNUALS, &c., *see p.* 33.
CALENDARS and COLLEGE REPORTS, *see p.* 34
PHOTOGRAPHS, *see p.* 35.
PUBLICATIONS OF SOCIETIES, &c., *see p.* 35.
PERIODICALS, *see p.* 39.

BOOKS (in order received).

The Administration of Industrial Enterprises, with special reference to Factory Practice, by Edward D. Jones, Ph.D.; from the publishers.

Some of the Writings of John A. Hill; from Mr. C. W. Dibble.

The Flying-Machine from an Engineering Standpoint (2 copies), by F. W. Lanchester; from the author and publisher.

Modern Workshop Practice (3rd ed.), by Ernest Pull; from the publishers.

Steam Turbines (2 copies), by W. J. Goudie, B.Sc.; from the author and publishers.

Practical Shipbuilding: a Treatise on the Structural Design and Building of Modern Steel Vessels (2 vols. Text and Plates), by A. Campbell Holms.

Modern Gasworks Practice, by Alwyne Meade.

The Value of Science in the Smithy and Forge (2nd ed.), by W. H. Cathcart; from the author.

Turbines Applied to Marine Propulsion (2nd ed.), by Stanley J. Reed; from the publishers.

Electrical Engineering Practice (3rd ed.), by J. W. Meares; from the author.

A Practical Manual of Autogenous Welding (Oxy-Acetylene), by R. Granjon and P. Rosemberg; translated from the French by G. Richardson.

Railway Maintenance Engineering with Notes on Construction, by William H. Sellew; from the publishers.

Text-Book on Motor Car Engineering:—Vol. II, Design, by A. Graham Clark.

A Rational Wages System, by Henry Atkinson; from the author.

The John Fritz Medal. Biographical Notices of the John Fritz Medallists, edited by Rossiter W. Raymond, Ph.D., LL.D.; from the Board of Award.

Temperatuurmetingen in een Dieselmotor, by E. B. Wolff; from the author.

Scientific Treatise on Smoke Abatement, by H. Hamilton; from the author.

Researches on the Carbides in Steel made between 1894 and 1915, by Prof. J. O. Arnold, D.Met., F.R.S., and Prof. A. A. Read, M.Met., F.I.C.; from Prof. J. O. Arnold, D.Met., F.R.S.

Flour-Milling, by Peter A. Kozmin.

Useful Engineers' Constants for the Slide Rule and how they are obtained (2nd ed.), by J. A. Burns; from the author.

Some Modern Methods of Ventilation with Special Reference to Public Buildings, by R. Grierson; from the author.

The Aviation Pocket-Book, 1917, by R. Borlase Matthews.

Machinery's Screw Thread Books (2nd ed.), by C. Edgar Allen; from the author.

Continuous-Current Motors and Control Apparatus, by W. Perren Maycock; from the publishers.

Power Wiring Diagrams: A Handbook of Connection Diagrams of Control and Protective Systems for Industrial Plants, by A. T. Dover; from the publishers.

How to Save a Big Ship from Sinking, by Charles V. A. Eley; from the author.

The Education of Engineers, by H. G. Taylor; from the author.

OFFICIAL PUBLICATIONS.

British Isles.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Draft of Proposed Revised Regulations for Continuation, Technical and Art Courses; Regulations for Secondary Schools; Report of the Board of

Education for the year 1915–16; Engineering Training: some notes on existing facilities; Reports on the Science Museum, the Geological Survey, and the Museum of Practical Geology; from the Board of Education.

Industrial Research in the United States of America (No. 1); Report on the Resources and Production of Iron Ores and other principal Metalliferous Ores used in the Iron and Steel Industry of the United Kingdom; Report of the Committee of the Privy Council for Scientific and Industrial Research 1916–17; from the Department of Industrial and Scientific Research.

British Meteorological and Magnetic Year Book, 1911, Part V:—Réseau Mondial (text and plates); Réseau Mondial, 1912; from the Meteorological Office.

Health and Welfare of Munition Workers outside the Factory (17); Further Statistical Information Concerning Output in Relation to Hours of Work, with special reference to the Influence of Sunday Labour (18, appendix to 5); Investigation of Workers' Food and suggestions as to Dietary (19, second appendix to 3—Industrial Canteens); Weekly hours of Employment (20, supplementary to 5—Hours of Work); Industrial Efficiency and Fatigue (Interim Report); from the Ministry of Munitions.

The Nitrogen Problem and the Work of the Nitrogen Products Committee; from the Munitions Invention Department.

War Office Weekly Casualty List, Nos. 1 to 20.

Illustrated Official Journal (Patents); from H.M. Patent Office.

Africa.

Twenty-second Annual Report of the Rhodesia Chamber of Mines for the year ended 31st December 1916; from the Rhodesia Chamber of Mines.

Report of the Departmental Committee on Underground Mining Contracts (Witwatersrand Mines), Pretoria, 1917; Department of Mines and Industries, Annual Report of the Government Mining Engineer, 31st December 1916; from the Union of South Africa.

Municipal Council of Johannesburg—Annual Report of the Town Engineer for the year ended 30th June 1916; from Mr. G. S. Burt Andrews.

Twelfth Annual Report of the Rand Water Board for the Financial Year ended 31st March 1917; from Mr. William Ingham (Johannesburg).

Argentine Republic.

Boletins Tome XV, 1 to 6; from the Ministerio de Obras Públicas.

Boletin Mensual, Tome I, Nos. 6 and 9; from the Ministerio de Agricultura de la Nación.

Australia.

Australian Official Journal of Patents; from the Department of Patents of the Commonwealth of Australia.

The Mathematical Theory of Population, of its Character, and Fluctuations, and of the Factors which influence them (Appendix A, Vol. I, Census of the Commonwealth of Australia), by G. H. Knibbs, C.M.G., F.S.S., F.R.A.S.; from the author.

Report by the Department of Public Works for the years ended 30th June 1915 and 1916; Annual Reports of the Department of Mines for the years ended 1915 and 1916; Report of the Commissioners, New South Wales, Government Railways and Tramways, for the year ended 30th June 1917; from the Government of New South Wales.

Annual Report of the Under-Secretary to the Hon. Alf. J. Jones, M.L.C., for the year 1916; Mining Journal; from the Government of Queensland.

Report of the Engineer-in-Chief for 1915 and 1916; from the Government of Tasmania.

Monthly Mining Report; from the Government of Victoria.

Water Supply, Sewerage and Drainage Department, Fourth Annual Report 1915–16; Report on the Working of the Government Railways and Tramways for the year ended 30th June 1916; Report of the Department of Mines for the year 1915; Geological Survey Bulletin, Nos. 60, 63, 66; from the Government of Western Australia.

Canada.

Twenty-fifth Annual Report of the Ontario Bureau of Mines, 1916, Vol. XXV, Parts I and III; also various Bulletins, Memoirs and Reports of the Department of Mines, Ottawa; from the Government of Canada; Report on Copper and Zinc Refining in Canada; from Mr. David Carnegie.

India.

Report of the Chief Inspector of Mines in India under the Indian Mines Act (VIII of 1901) for the year ending 31st December 1916; from the Government of India.

Classified List and Distribution Returns of Establishment, Indian Public Works Department, to 31st December 1916 and 30th June 1917; Classified List of State Railways, 31st December 1916 and 30th June 1917; from the Registrar.

Eleventh Annual Report of the Bengal Smoke-Nuisances Commission for the year 1916–17 (3 copies); from Mr. John Robson.

United States.

Eleventh Annual Report of the Board of Water Supply of the City of New York, 31st December 1916; Catskill Water Supply—A General Description and Brief History; from the Board of Water Supply.

Bureau of Mines, Bulletin 142; Technical Papers, Nos. 149, 156, 169, 177; from the Bureau.

Bureau of Standards, Technical Papers, Nos. 33, 58, 70, and 84; from the Department of Commerce.

Mineral Resources (11 pamphlets); Water Supply Papers (4 pamphlets); Bulletins (14 pamphlets); Professional Papers (2 pamphlets); from the U.S. Geological Survey.

Official Gazette; from the United States Patent Office.

PAMPHLETS.

The Life and Work of Joseph Hall, 1789-1859, the Inventor of the Modern System of Puddling, by John W. Hall; from the author.

Industrial Engineering: Present Position and Post-War Outlook, by F. W. Lanchester; from the author.

The Corrosion and Electrical Properties of Steel, by Sir Robert A. Hadfield, F.R.S., and Edgar Newbury, D.Sc.; from Sir Robert A. Hadfield, F.R.S.

The Channel Tunnel: Military Aspect of the Question; The Channel Tunnel and the World War; from the Channel Tunnel Co. (A second copy of each received from Mr. W. J. Botterill.)

Germany's Trade Methods—Cartels and Syndicate, by Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S.; from the author.

Part-Time Secondary Education, an Address, by J. C. Maxwell Garnet; from the author.

Some Points Regarding the Testing of Iron and Steel, by Professor Archibald Barr, D.Sc.; from the author.

Collection of Old Newspaper Cuttings relating to George and Robert Stephenson; from Mr. B. A. Raworth.

Thermal Researches on Casting and Moulding Sand, by Masatosi Ôkôchi; Ueber die Warmespannung im Geschützrohre, by Masatosi Ôkôchi; On the Resistance of Rifling of Small Arms, by Masatosi Ôkôchi; Torsional Strength of Steel Bars Beyond the Elastic Limit, by Masatosi Ôkôchi and Masaichi Majima; Beiträge zur Schwingung der Gewehrlaufs, by Masatosi Ôkôchi and Masaichi Majima; from Professor Viscount Masatosi Ôkôchi.

Composition of Power Gases, by W. A. Tookey; from the author.

The History of the Sugar Machinery Industry in Glasgow, by Robert Harvey; from the author.

Further Notes on Cast Iron Growth, by Professor H. C. H. Carpenter, M.A., Ph.D., A.R.S.M.; from the author.

The Decimal System of Coinage, Weights and Measures, by Harry Allcock; from the author.

The Future of Drawing in Scientific Work and in General Education; from Mr. J. P. Magiunis.

Industrial Fatigue in its Relation to Maximum Output, by Professor Henry J. Spooner; from the Labour Co-partnership Association.

Irrigation in Lybia (Italian Colony): Italian Irrigation; by Professor Luigi Luiggi, D.Sc.; from the author.

German Weaving Mills: the Distribution of Production, by Mr. Oscar S. Hall; from the author.

Presidential Address, The Institution of Automobile Engineers, by L. A. Legros; from the author.

Report of the Fuel Research Board on their Scheme of Research and on the Establishment of a Fuel Research Station; from the Department of Scientific and Industrial Research.

Specification of John Birkenshaw's Patent, for an improvement in the Construction of Malleable Iron Rails, to be used in Rail Roads: with Remarks on the comparative merits of Cast Metal and Malleable Iron Rail-Ways (2 eds., 1822 and 1824—the latter with 8 pp. of correspondence); from Mr. Michael Longridge.

Steels used in Aero Work, by Dr. W. H. Hatfield; from the author.

Some Aspects of Industrial Fatigue, by Professor Henry J. Spooner; Industrial Fatigue in its Relation to Maximum Output: Fore Words by Sir Robert A. Hadfield, F.R.S., and Mr. J. R. Clynes, M.P., by Professor Henry J. Spooner; from the author.

The Commercial Aspect of Engineering in China, by S. W. B. McGregor; from the author.

The Inspection of Screw Gauges for Munitions of War, by H. J. Bingham Powell; from the author.

Baldwin Locomotive Works: Records of Recent Construction, Nos. 85, 86, 87.

DIRECTORIES, ANNUALS, REFERENCE INDEXES, &c.

The Athenæum Subject Index to Periodicals: Historical, Political and Economic Sciences; from the publishers.

Directory of Directors, 1917.

Electrical and Allied Trades Directory (The Red Book), 1917; from the publishers.

The Engineering Index Annual for 1916, and monthly issues for 1917; from the publishers.

The Engineer's Year-book, 1917, by H. R. Kempe; from the editor and proprietors.

Garcke's Manual of Electrical Undertakings, 1917–18.

International Catalogue of Scientific Literature (C = Physics).

Kelly's Directory of the Engineers, Iron and Metal and Electrical Trades, 1917.

Kelly's Post Office London Directory, 1918.

London Master Builders' Association, Handbook and Diary, 1917.

The Motor, Marine and Aircraft Red Book, 1917; from the publishers.

Official Year-book of the Scientific and Learned Societies, 1916.

Stock Exchange Year Book, 1917.

Whitaker's Almanack, 1918.

Who's Who, 1918.

CALENDARS AND COLLEGE REPORTS

(from the respective Authorities).

British Isles.

University of Birmingham; Calendar 1916–17.

City of Bradford Technical College; Prospectus 1917–18.

University College of South Wales and Mon., Cardiff; Calendar 1916–17.

Edinburgh University; Calendar 1917–18.

Glasgow University; Calendar 1917–18.

University of Leeds; Report 1915–16.

City and Guilds of London Institute; Prospectus 1917, and "The Central."

Imperial College of Science and Technology; Calendar 1917–18, Prospectus 1917, and List of Past and Present Students and Staff who have joined His Majesty's Forces, June 1917.

King's College, London; Calendar 1917–18.

University College, London; Calendar 1917–18.

Victoria University of Manchester; Calendar 1917–18.

University of Sheffield; Calendar 1917–18.

Australia.

South Australian School of Mines and Industries and Technological Museum; Annual Report, 1916.

China.

University of Hongkong; Calendar 1916–17.

Japan.

Imperial University of Kyashu, Fukuoka; Vol. I, No. 3.
Imperial University of Tokyo; Journal, Vol. 9, No. 2.

United States.

University of Cincinnati; 7 pamphlets.
Cornell University; Librarian's Report 1915–16.
*University of Illinois, Urbana; Bulletins.
Michigan College of Mines, Houghton, Michigan; Year-Book 1916–17.

PHOTOGRAPHS.

Photo of Turbine built in the Fen District about 1870–80; from Mr. Bernard Asplen.
Album of Views of the Installations in Buenos Aires of the Compañia Italo-Argentina de Electricidad.

PERIODICAL PUBLICATIONS OF SOCIETIES, &c.

(*Those marked* * *are bound for preservation in the Library.*)

British Isles.

Aeronautical Institute of Great Britain, "Air."
Aëronautical Journal.
Board of Scientific Societies; Minutes.
*British Association for the Advancement of Science; Report.
Cambridge University Library; Report 1916.
*Chemical Industry, Society of; Journal.
Chemistry of Great Britain and Ireland, Institute of; Proceedings.
*Civil Engineers, Institution of; Proceedings.
Cleveland Institution of Engineers, Middlesbrough; Proceedings.
Consulting Engineers, Association of; Reports.
*Electrical Engineers, Institution of; Journal.
Engineering Standards Committee; Reports Nos. 45, 71, 72, 74, 78, 80, C. L. 3750.
*Engineers, Society of; Transactions.
*Engineers and Shipbuilders in Scotland, Institution of, Glasgow; Transactions.
*Gas Engineers, Institution of; Transactions.
Huddersfield Engineering Society; Proceedings.
*Iron and Steel Institute; Journal and Carnegie Scholarship Memoirs, Vol. VIII.

*Literary and Philosophical Society of Manchester; Memoirs and Proceedings.
*Liverpool Engineering Society; Transactions.
Locomotive Engineers, Institution of; Journal.
*Manchester Association of Engineers; Transactions.
*Manchester Steam Users' Association; Annual Report and Memorandum.
*Marine Engineers, Institute of; Transactions.
*Metals, Institute of; Journal.
*Mining Engineers, Institution of; Transactions.
*Mining and Metallurgy, Institution of; Bulletin.
*Municipal and County Engineers, Institution of; Journal.
National Physical Laboratory; Report 1916-17; Collected Researches, Vol. XIII.
*Naval Architects, Institution of; Transactions and List of Members 1917.
*North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne; List of Members 1917.
*Patent Agents, Chartered Institute of; Transactions.
Permanent Way Institution; Journal.
Petroleum Technologists, Institution of; Journal.
*Physical Society of London; Proceedings.
Post Office Electrical Engineers; Journal.
Radcliffe Library, Oxford; Catalogue of Additions during 1916.
*Royal Agricultural Society of England; Journal.
*Royal Artillery Institution, Woolwich; Journal.
*Royal Cornwall Polytechnic Society; Report.
*Royal Institute of British Architects; Journal.
*Royal Institution of Great Britain; Proceedings.
Royal Irish Academy; Proceedings.
Royal Microscopical Society; Journal.
*Royal Philosophical Society of Glasgow; Proceedings.
*Royal Sanitary Institute; Journal.
*Royal Society of Arts; Journal.
*Royal Society of Edinburgh; Proceedings.
*Royal Society of London; Proceedings (A), Year-Book 1917, and Philosophical Transactions.
*Royal United Service Institution; Journal.
*Science Abstracts—Physics and Electrical Engineering.
Sheffield Society of Engineers and Metallurgists; Proceedings.
South Wales Institute of Engineers, Cardiff; Proceedings.
*Staffordshire Iron and Steel Institute, Tipton; Proceedings.
*Surveyors' Institution; Transactions, Professional Notes, and Report of Housing Committee.
Tramways and Light Railways Association; Journal.

*Water Engineers, Institution of; Transactions.
*West of Scotland Iron and Steel Institute, Glasgow; Journal.

Other Countries (alphabetical).

Africa.

*Chemical, Metallurgical and Mining Society of South Africa, Johannesburg; Journal.
*South African Institution of Engineers, Johannesburg; Journal.

Australia.

*Australasian Institute of Mining Engineers; Proceedings.
*Engineering Association of New South Wales; Proceedings.
*Northern Engineering Institute of New South Wales; Proceedings, Annual Report 1917, and various Papers.
*Royal Society of New South Wales; Journal.

Canada.

*Canadian Society of Civil Engineers; Transactions.
Revue Trimestrielle Canadienne.
*Royal Society of Canada, Ottawa; Transactions and Memoirs.

France.

*Académie des Sciences, Paris; Comptes Rendus des Séances.
*Annales des Mines, Paris.
*Annales des Ponts et Chaussées, Paris.
Association Française du Froid; "Le Froid."
*Association Française pour l'Avancement des Sciences, Paris; Conférences, 1916–17.
*Société d'Encouragement pour l'Industrie Nationale, Paris; Bulletin.
*Société Industrielle de Rouen; Bulletin.
*Société des Ingénieurs Civils de France, Paris; Bulletin.

Holland.

*Tijdschrift van het Koninklijk Instituut van Ingenieurs, 's Gravenhage; List of Members.

India.

*Committee of the Locomotive, Carriage and Wagon Superintendents of Indian Railways, Madras; Proceedings.

Italy.

*Associazione Elettrotechnica Italiana, "L'Elettrotecnica," Milan.
Atti del Collegio degli Ingegneri ed Architetti in Milano.
Rivista Tecnica delle Ferrovie Italiane, Roma.
*Società degli Ingegneri e degli Architetti Italiani, Roma; Annali d' Ingegneria.

Japan.

Society of Mechanical Engineers, Tokyo; Journal.

New Zealand.

New Zealand Society of Civil Engineers, Wellington; Proceedings.

Norway.

Teknisk Ukeblad, Christiania.

Sweden.

*Svenska Teknologföreningen, Stockholm.

United States.

*American Institute of Electrical Engineers, New York; Proceedings, Transactions; and Year Book, 1917.
*American Institute of Metals, Depew; Transactions.
*American Philosophical Society, Philadelphia; Proceedings.
*American Society of Civil Engineers, New York; Proceedings and Transactions.
*American Society of Mechanical Engineers, New York; Journal.
*American Society of Naval Engineers, Washington; Journal.
*American Society of Refrigerating Engineers, New York; Transactions.
Cleveland Engineering Society; Journal.
John Crerar Library, Chicago; Report 1916.
*Engineers' Club, Philadelphia; Proceedings.
Engineers' Club of St. Louis; Journal.
*Engineers' Society of Western Pennsylvania, Pittsburgh; Proceedings.
*Franklin Institute, Philadelphia; Journal.
*Library of Congress, Washington; Report 1916, Publications issued since 1897.
Library of Stone and Webster, Boston; Journal.
Michigan Technic.
National Academy of Sciences, Washington; Proceedings.
*New York Railroad Club; Official Proceedings.

St. Louis Railway Club; Official Proceedings.
*Smithsonian Institution, Washington; Annual Report 1915.
Stevens Indicator, Hoboken, N.J.
*Traveling Engineers' Association; Proceedings.
*United States Artillery, Fort Monroe; Journal.
*United States Naval Institute, Annapolis; Proceedings.
*Western Society of Engineers, Chicago; Journal.

OTHER PERIODICALS.

(*Those marked * are bound for preservation in the Library.*)

British Isles.

Aeronautics.
Aeroplane.
Arms and Explosives.
*Autocar.
*Automobile Engineer.
*Auto-motor Journal.
Beama Journal.
*Builder.
*Cassier's Engineering Monthly.
Civil Engineering.
Coal and Iron and By-Products Journal.
Cold Storage and Produce Review.
*Colliery Guardian.
*Commercial Motor.
*Concrete and Constructional Engineering.
Domestic Engineering.
Electric Vehicle.
Electrical Industries and Investments.
*Electrical Review.
*Electrical Times.
*Electrician.
*Engineer.
Engineer and Iron Trades Advertiser.
*Engineering, and Directory.
*Engineering Review.
Ferro-Concrete.
Fireman.
Fishing Gazette.
*Flight.
*Foundry Trade Journal and Pattern-Maker.
*Gas Journal.
Gas and Oil Power.
Gas World.
Ice and Cold Storage.
Illuminating Engineer.
Industrial Engineer.
Irish Builder and Engineer.
*Iron and Coal Trades Review.
Iron and Steel Trades Journal and Iron Trade Circular.
Ironmonger, and Diary 1917.
Junior Mechanics and Electricity.
Kahncrete Engineering.
Locomotive Magazine.
London and China Express with supplement.
London County Council Gazette.
*Machinery.
*Marine Engineer.
Marine Magazine.
*Mechanical Engineer.

*Mechanical World.
*Mining Journal.
Model Engineer and Electrician.
*Motor Ship and Motor Boat.
*Motor Traction.
*Nature.
Page's Engineering Weekly.
*Philosophical Magazine and Journal of Science.
*Plumber and Decorator.
*Power User.
*Practical Engineer.
Quarry.
*Railway Gazette.
Railway News.
*Shipbuilder.
*Shipbuilding and Shipping Record.
*Shipping World.
South African Engineering.
*Steamship.
Surveyor.
Syren and Shipping Illustrated.
*Textile Recorder.
Times and Engineering Supplement.
Tramway and Railway World.
Vulcan.
Water.
*Wireless World.

Other Countries (alphabetical).

Canada.

Canadian Engineer.
Canadian Machinery and Manufacturing News.
Canadian Manufacturer.

France.

*Génie Civil.

Holland.

De Ingenieur.

Italy.

*Giornale del Genio Civile.

New Zealand.

Progress.

Russia.

Извѣстія Собранія Инженеровъ Путей Сообщенія.

Switzerland.

*Revue Polytechnique Schweizerische Bauzeitun

United States.

*American Machinist.
Automobile.
*Brotherhood of Locomotive Firemen's Magazine.
*Electric Railway Journal.
Electrical Review.
*Electrical World.
*Engineering News.
*Foundry.
Gas Engine.
*General Electric Review.
*Industrial Management.
Machinery.
*Physical Review.
Popular Mechanics Magazine.
*Power.
Railway and Locomotive Engineering.
*Railway Mechanical Engineer.
*Railway Review.
*Scientific American.

The following Duplicates have been received for Loan Purposes.

Automobile Engineers, Institution of; Proceedings.
Civil Engineers, Institution of; Proceedings, Vols. ccii, cciii.
Electrical Engineers, Institution of; Journal.
Iron and Steel Institute; Journal.
Metals, Institute of; Journal.
South Wales Institute of Engineers; Proceedings.
American Society of Mechanical Engineers; Journal.

The Institution of Mechanical Engineers.

PROCEEDINGS.

January 1918.

An Ordinary General Meeting was held at The Institution of Civil Engineers, London, on Friday, 18th January 1918, at Six o'clock p.m.; Michael Longridge, Esq., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that, in accordance with Article 23, the President, two Vice-Presidents, and seven Members of Council would retire at the ensuing Annual General Meeting; and the complete list of those retiring was as follows:—

President.

Michael Longridge, ...	London.

Vice-Presidents.

William H. Allen, ...	Bedford.
J. Rossiter Hoyle, ...	Sheffield.

MEMBERS OF COUNCIL.

Sir J. WOLFE BARRY, K.C.B., LL.D., F.R.S., .	London.
Sir J. ALFRED EWING, K.C.B., LL.D., F.R.S., .	Edinburgh.
*EDWARD HOPKINSON, D.Sc., ...	Manchester.
HENRY A. IVATT, ...	Haywards Heath.
Eng. Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S., ...	London.
WALTER PITT, ...	Bath.
*RICHARD WILLIAMSON, ...	Workington.

All the foregoing, with the exception of Sir Alfred Ewing and Mr. Pitt, were hereby nominated by the Council for election, with their consent:—

The following Nominations were also made by the Council for election, with their consent:—

FOR MEMBERS OF COUNCIL.

Election as Member.		
1897.	DANIEL ADAMSON, ...	Hyde.
1897.	Sir HENRY FOWLER, K.B.E., . .	Farnborough.
1876.	J. W. RESTLER, ...	London.
1903.	DAVID E. ROBERTS, ...	Cardiff.
1901.	WILLIAM TAYLOR, ...	Leicester.

The PRESIDENT reminded the Meeting that, according to By-law 26, any Member or Associate Member was then entitled to add to the list of candidates.

No other names being added, the PRESIDENT announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The PRESIDENT announced that the following four Transferences had been made by the Council:—

* Appointed during the year.

Associate Members to Members.

BETTISON, FRANK CASSON, ...	Leeds.
BROWN, JOHN POLLOCK, ...	E. Croydon.
GRAHAM, JACK CURTIS, Lieut. R.N. . .	London.
PITMAN, PERCY HECTOR, ...	London.

The following Papers were read, that by Mr. Legros being presented in the form of a Lecture, illustrated by lantern slides:—

"Utility of Motor-Tractors for Tillage Purposes"; by ARTHUR AMOS, M.A., of the School of Agriculture, University of Cambridge.

"Traction on bad Roads or Land"; by L. A. LEGROS, of Acton, *Member*.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 71 Members and 37 Visitors.

Mr. LEGROS also presented his Paper in the form of a Lecture, illustrated by lantern slides:—

At MANCHESTER, in the Examination Hall, Municipal School of Technology, on Monday, 21st January. The Chair was occupied by the PRESIDENT.

At LEEDS, in the Philosophical Hall, on Tuesday, 29th January, when Mr. HENRY MCLAREN, *Member*, presided.

At LINCOLN, in the Theatre of the Municipal Technical School, on Friday, 8th February. Mr. F. H. LIVENS, *Member*, in the Chair.

UTILITY OF MOTOR-TRACTORS FOR TILLAGE PURPOSES.

By ARTHUR AMOS, M.A., of the School of Agriculture, University of Cambridge.

The chief value of the Motor-Tractor to the farmer is, that it enables him to get his ploughing done quickly when the texture of the land is best fitted for the work, instead of being compelled to continue ploughing with horses for long periods when soil and other conditions are not really fit. This gives the farmer two great advantages: first, the subsequent cultivations necessary to produce a seed-bed are reduced by perhaps 50 per cent.; and secondly, if a field is ploughed quickly after the previous crop is removed, weeds are prevented from overrunning the land and are consequently more easily kept in subjection.

At this stage it may be well to state the three most important factors which determine the texture or friability of any soil (there are others of lesser importance). These are, first, the size of the particles composing the soil; if the soil consists mostly of large and coarse particles, then the soil is generally friable and easy to cultivate, as for example, sandy and gravelly soils; but if the particles are small then the texture becomes more tenacious and sticky, and friability is bad; such soils are generally called clays. Between these two extremes all intermediate types of soil exist. Secondly, texture depends upon the degree of wetness of the soil; most soils when wet (especially the clays) are characterized by a tenacious sticky texture, require greater power for cultivation, and become pasty if cultivated, so that, subsequently, they are difficult

to convert into good seed-beds, because such a pasty condition prevents the clods from breaking. As the soil passes from a wet to a more dry yet "moist" condition, this sticky character disappears and the texture becomes more and more friable; in this condition the land is easy to plough, and the resultant ploughing is more easily converted into a good seed-bed. If, however, drying is continued and the soil becomes quite dry, it often sets so hard (especially on clay soils) that it becomes impossible to plough, and only very powerful cultivators, such as those drawn by steam-engines, are able to break the land. This dry condition of hard texture of the soil, however, presents one very marked contrast with the bad texture due to excessive wet, namely, that when such dry, hard soil is broken up and subsequently becomes moist with rain, it crumbles like a lump of quicklime into an ideal seed-bed. At present there is no motor-drawn implement which is able to deal with this hard condition of clay land, but it is not impossible that some new implement may be devised to act as a cultivator for use with high-speed engines under such conditions. Thirdly, the texture depends upon the previous cultivation of the land, whether it has been recently cultivated, in which case the depth of soil cultivated is loose, or whether it has become consolidated by long weathering and the trampling of carts, horses or sheep; in the former case the furrow is more easily turned, but the loose surface presents greater difficulties to the effective grip of the tractor wheels on the land, and movement may be impossible; in the latter case the work of the tractor is increased, but, as in the case of a clover stubble, the surface is so firm and solid that the wheels obtain a good grip.

From these considerations it is obvious that motor-tractors have to plough under a great variety of soil conditions, so that it is not to be expected that any one tractor will be the best under all circumstances. With this introduction, it is possible to examine some of the points of agricultural importance in the motor-tractor.

Power.—It would seem hardly necessary to emphasize the importance of the tractor being possessed of ample power, but

everyone may not appreciate how greatly the power required for ploughing different conditions of soil varies. Perhaps the case is best illustrated by reference to horse ploughing: on some light land 3 horses will plough 2 acres in a day's work, whereas on clay land the same 3 horses may only be able to plough ½ an acre in the same time. It follows that the ploughing of one soil may require four times the power required by the other, and a tractor that does good work on the one will fail completely on the other.

The logical conclusion from this would seem to be that one type of tractor should be designed for the light land and another for the heavy land, but whilst this may be carried into practice to some extent, it cannot completely solve the difficulty, for on very many farms some of the fields are composed of heavy and some of light land, and moreover in the same field the texture of the soil may suddenly change as one passes from one soil type to the next. These difficulties may be overcome, partly by using a plough with fewer breasts for ploughing heavy land, partly by changing speed when the soil varies, but much the most sensible solution of the difficulty is by fitting the tractors with engines capable of developing ample power for the work for which they are designed; for 3-furrow ploughing at least 20 b.h.p. is required, and 30 b.h.p. is not too much on some types of soil.

Weight.—The tractors in use in England at the present time vary greatly in weight, from about 20 cwt. up to 5 tons. From two points of view, weight is advantageous, thus weight generally signifies greater strength in construction and less wear and tear; again, a heavy tractor can often obtain a better foothold than a light one upon the land over which it travels. On the other hand, a heavy tractor when used for ploughing suffers in comparison with light tractors in three distinct respects. First, a heavy tractor must consume a considerable portion of its power in merely transporting itself across the field, and this consumption of power increases very greatly when the surface is soft and the "going" is bad; secondly, the dead weight of the tractor is a very serious handicap upon hilly land, whether, as is usual, the ploughing is

done directly up and down hill, or whether it is done across the slope, in which case the heavy tractor tends to slide down hill; thirdly, and this is the most serious reason agriculturally, a heavy tractor may do untold damage to the texture of the soil over which it travels. The Author proposes to explain the conditions under which this damage to the texture of the soil occurs in some detail.

When the soil is dry, no matter whether it be a light or a heavy soil, the pressure of heavy tractor wheels on the soil occasions no damage to the texture of the soil, but when the soil is moist or wet then the pressure of the wheels tends to squeeze and paste the soil into a consistency resembling brick-earth "pug" (the condition into which brick-earth is worked before being moulded into the shape of bricks). This condition is fatal to the production of a seed-bed and to the growth of crops, and, if produced on heavy land, may take a rotation of crops (say 5 years) to rectify. On light soils this condition is much less likely to occur, and if it occurs can be much more quickly rectified.

On light soils generally, and on other soils in a dry state, therefore, a tractor weighing 3 to 5 tons may be quite admissible, but for ploughing heavy land or loams in moist condition such heavy tractors, unless provided with caterpillar wheels (and these do not obviate the damage completely), are unsuitable. For such ploughing, tractors weighing 30 cwt. or less are more suitable, and even these must be used with discretion; unfortunately, so far as the Author is aware, only one such tractor with sufficient power, and this in very small numbers, is available.

The conclusions to be drawn from these remarks are twofold: first, that actual strength required in the construction of different parts of the tractor shall be accurately determined by experiment; secondly, that when this is known, the framework shall be liberally composed of best steel instead of iron, so that weight may be reduced.

Speed.—Perhaps the most important factor upon which the rate of ploughing depends is the speed at which the tractor travels; the greater the speed the greater the area accomplished; consequently,

it is desirable to obtain as high a speed as possible unless this advantage is counterbalanced by some disadvantage. A further reason for maintaining a comparatively high speed is that the friction exerted between the soil, on the one hand, and the various parts of the plough in contact with it, is a function of the areas in contact at any one time and not of the length of furrow ploughed per unit of time; consequently, a plough hauled at a comparatively high speed experiences no greater friction than one hauled at a low speed. It should be of course stated that the plough does other work besides overcoming friction, which is not reduced by greater speed.

In the case of horse-ploughing the best speed is largely decided by the speed at which the horses can develop their greatest power and this has been shown to be between 2 and $2\frac{1}{2}$ (the normal rate of horse-ploughing is about 2) miles per hour, as a result of this nearly all types of ploughs have been evolved to suit this speed, and it by no means follows that this form of plough is the best for ploughing at a speed of 3 or $3\frac{1}{2}$ miles per hour, a speed at which tractors might well work; certain it is that some ploughs hauled at such speeds by motor-tractors accomplish very bad ploughing. Nevertheless, because of the eminent advantages of this higher speed, it is desirable that both tractor-makers and plough-makers should consider these points, and test such problems experimentally.

Wheels and Grip.—When the surface of the land is dry and solid, tractor-wheels experience little difficulty in obtaining an efficient grip of the surface, but when the surface is loosened by previous tillage or by wet weather, the difficulty of obtaining foothold is very great. A variety of devices have been tried for overcoming this difficulty, most of which may be classified under two headings: first, extending the area of contact between the wheel and the surface of the soil, and, secondly, by attaching grips or studs to the wheel surface so as to obtain greater friction.

The former of these objects may be obtained either by using driving wheels of large diameter or with wide tread, but the best

method of improving the grip on this principle is by adopting the chain-track device. Theoretically this is an ideal method of attaining the end in view, and in practice the method succeeds and gives to the tractor the best grip on a loose or slippery surface; but one practical difficulty arises, namely, that grit and dirt is always present in the bearings and working parts between the drive and the tracks, which consequently undergo rapid wear and tear. But because this method does give the best grip, and because it also enables the weight of the tractor to be distributed over a wider area and thus prevents packing of the soil, it is worthy of extended trial and experiment to minimize this adverse feature of wear and tear.

The second means of overcoming slipping by means of grips or studs attached to the outside of the driving wheels needs careful consideration. It should be recognized that such studs or grips press upon the soil in two directions as the wheel revolves, partly by a vertical pressure and partly by a lateral pressure, and in general it may be said that the vertical pressure by consolidating the soil is harmful, whereas the lateral pressure has a stirring tendency which may be beneficial, especially when one driving wheel runs on the subsoil in the open furrow. It follows that blunt studs should be avoided, and that more pointed and perhaps longer studs or grips will occasion less damage to the soil.

In the case of the lighter motor-ploughs and tractors, it is worth mentioning that the practice of running one driving wheel in the open furrow (provided it is not so wide as to press on the furrow already turned) is desirable, because in this position the soil during the ploughing season is firmer and generally drier.

Turning at Headlands.—One of the most serious drawbacks in the use of the motor-tractor with the common type of multiple plough is the necessity for wide headlands; many of the tractors require one of from 6 to 10 yards according to the type of tractor, because they are unable to turn short. A further consequence of this is that the motor-tractor has to travel a long distance along the headland, on the average 30 to 40 yards at each end in the

case of heavy tractors, and perhaps 20 yards in the case of light tractors. Now the average length of plough furrow will be about 200 yards, and assuming the run along the headland averages 30 yards, the time lost at the headland will amount to one-seventh of the running time of the tractor. This is a very serious waste of time.

The difficulty does not arise in the case of steam ploughing, because for this purpose a balanced-plough is used which simply requires to be toppled over at each end, and it seems to the Author that no insurmountable difficulty would be experienced in designing such a 3 or 4 furrow balanced-plough for use with motor power. Such a motor-plough would need to have the motor placed in the centre of the implement; it would need reverse gears similar and equal to the forward gears, and would need two sets of controls; the ploughs would be balanced before and behind.

The advantages of such a machine for purposes of motor ploughing are very great, some of the more important are enumerated below:—

1. Time lost in turning would be greatly reduced.
2. The headlands could be reduced to very narrow limits.
3. The headlands would not be crushed by frequent passage of the motor upon them.
4. The plough would start at one side of the field and work back and forward until the opposite side was reached. All the furrows would be turned in one direction; there would be no ridges, no open furrows, and no awkward narrow widths left for the horses to finish.

In conclusion, the Author has tried to indicate some of the problems, partly agricultural, partly mechanical, which need solution in order that motor-tractor ploughing may become more efficient. There is, he believes, no public Institution whose business it is to investigate such problems, and private firms have little time. It is to be hoped that the Board of Agriculture will shortly complete its scheme for founding an Institute of Agricultural Mechanism for research in, and testing of, new agricultural machinery, of which motor-ploughs form only one branch.

[The Paper by Mr. L. A. LEGROS was then presented in the form of a Lecture, and follows this in the Proceedings.]

Vote of Thanks.

The PRESIDENT remarked that it was scarcely necessary for him to ask the members to pass a hearty vote of thanks to the Authors of the two Papers which had just been read; he was sure they would gladly do so. The first Paper brought with it a suggestion of the country and country air, and taught a good deal about soils and the effect upon growth, which many present had probably never thought about before.

The second Paper gave much information about what was being done in the tractor world, especially in America, and here again was much that in all probability members had not previously known. He thought that those who had attended the Meeting had learnt a good deal, and were much indebted to the two Authors, to whom, therefore, he would ask the Meeting to pass a hearty vote of thanks.

The resolution of thanks was carried by acclamation.

[*The Discussion on Mr. Amos' Paper will be incorporated with that on the Paper by Mr. Legros.*]

TRACTION ON BAD ROADS OR LAND.

By L. A. LEGROS, of Acton, *Member*.

The problems involved in the design of vehicles for travelling, or for the haulage of goods, or agricultural implements, or produce over the land or bad roads, depend for their satisfactory solution upon conditions that vary widely. The worse the condition of the road or land to be traversed, the more essential it is that due account should be taken of the nature of the ground, its inequalities, its resistance to load and to those shearing forces to which its surface is subjected by tractive effort.

The methods adopted for overcoming the difficulties peculiar to such traction problems can be divided into two main classes: the one class is that in which the driving power is distributed over more than two driving wheels; the other class is that in which the tractor drives through chain-tracks which reduce the insistent load. The two classes of tractor are, consequently, applicable to different conditions, and while the methods cannot be considered as competitive, the limitations of each can be best appreciated by direct comparison of their respective peculiarities and advantages.

Under the ideal conditions of traction on rails, the driving power transmitted through a single pair of wheels may suffice to haul a train of many coaches or wagons. Under the less favourable conditions of ordinary roads, a single pair of driving wheels may serve to transmit the power necessary for hauling two or more trailers. Traction on the ordinary road by metal-tyred wheels,

however, demands in the driving wheels a large diameter and great width of tread, in order that the insistent load may be reduced to reasonable intensity. How sensitive roads are to the loads that they carry may perhaps be best realized by considering a gravel road, on which ordinary devices can, in normal conditions, be used safely; the same devices may, however, cause serious damage when the load-carrying coefficient is even slightly disturbed, as, for example, by a thaw.

Among schemes for road haulage devised with the object of reducing the load per driving wheel may be mentioned the Renard road-train,* consisting of 6-wheeled vehicles. The central wheels of each vehicle were metal-tyred driving wheels, and the end wheels were fitted with rubber tyres and Ackermann steering.† The leading vehicle formed the power unit, and power was transmitted to the central axles of the other vehicles of the train by an articulated shaft. Under State subsidy the system had a fair trial in France, but it has not developed to any notable extent. The attempts at multiple-axle drive have, however, indirectly led to the development of the four-wheel drive, a system which, while less ambitious, has considerable advantages for some conditions of traction over the ordinary two-wheel drive.

PART I.

Four-Wheel Drive.

The four-wheel drive may be combined with either two-wheel steering or four-wheel steering. An example of the first of these classes, schemes for which were proposed as early as 1898, was the touring car built by Spyker of Amsterdam in 1903, and exhibited at the Crystal Palace in 1904. The Author has already referred to this in the discussion on a Paper by M. Brillié read before the

* Proceedings Inst. of Automobile Engineers, vol. ii, pages 8, 18, 27, and vol. v, page 15; also Appendix I, Historical Note, page 136.

† *Engineering*, vol. 83, pages 237 and 408 (1907), and Appendix I, p. 136.

Institution.* M. Brillié's Paper treated of an improved motor lorry of the second of these classes, driving and steering through all four wheels.

The four-wheel drive vehicles of to-day have much in common with the ordinary back-axle driven lorry, or truck, in type and arrangement of the engine and its accessories, such as carburettor, radiator and clutch, and also in the arrangements of gear-box, springing and brakes. Those features only will be described, therefore, in which the four-wheel driven vehicle differs from the ordinary type.

FOUR-WHEEL STEERING.

In the ordinary front-steering vehicle, fitted with the Ackermann axle, the design endeavours to meet the condition that in plan the axes of both front wheels shall intersect at a point on the axis of the back wheels, as shown in Fig. 1 (page 58).† In the four-wheel drive car with four-wheel steering the problem assumes a more general form, and the condition to be met is that the axes of all four wheels shall intersect at the same point, Fig. 2. So long as this condition is fulfilled it is not essential that the inclination of the axes to the normal shall be the same for the front and back axles; but in practice the steering is generally symmetrical, Fig. 3, and the virtual centre about which the vehicle turns is situated on the normal centre line. This results in a reduction of the radius of the turning circle approximately to one half of that obtained with the same front axle and with front steering only. The vehicle has therefore much greater handiness in certain respects, but is subject to the disadvantage that if brought near a kerb, and particularly a high kerb, the wheels cannot be locked sufficiently to permit of taking a small turning circle in leaving. This can be a distinct disadvantage in cities, though it is to a great extent compensated for by the greater ease with which the vehicle can be manœuvred backwards.

* Proceedings, I.Mech.E., 1914, page 589.

† *See* "Road Locomotion," by Dr. H. S. Hele-Shaw, Proceedings, I.Mech.E., 1900, pages 200 *et seq.* and Plate 32.

The locking of the rear wheels restricts the space available for framing the body of the vehicle at the height of the chassis to a narrower width than with two-wheel steering. This does not affect the arrangement of a cylindrical tank or hopper-shaped body, but for the ordinary flat platform it is necessary to give greater height than in normal practice. Although the Author has not found an actual example of the non-symmetrical steering, shown in Fig. 2, it is to be noted that conversion to this arrangement involves

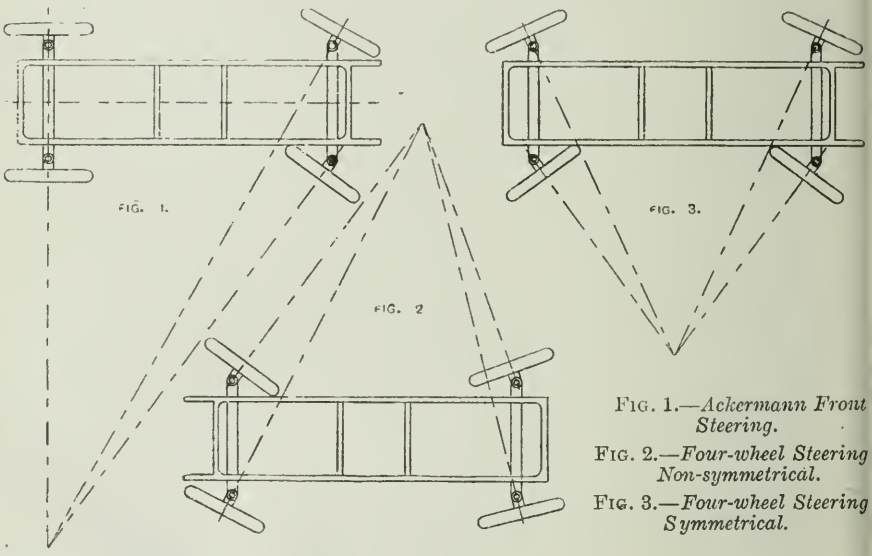


FIG. 1.—*Ackermann Front Steering.*

FIG. 2.—*Four-wheel Steering Non-symmetrical.*

FIG. 3.—*Four-wheel Steering Symmetrical.*

nothing more than altering the lengths of two levers, and that the increased width of body which could be carried direct on the chassis might well compensate for the slight increase in the turning radius.

For driving over country roads or fields with many irregularities or obstacles the four-wheel drive has undoubted advantages due to the fact that the percentage of load available for adhesion is nearly double that of a two-wheel drive.

FOUR-WHEEL BRAKING.

The application of brakes on automobile vehicles running on ordinary or bad roads involves inevitably the possibility of side-slip. It is well-known that, when the coefficient of friction for lateral displacement of the tyres is small, and the brakes are applied too hard on a vehicle with rear wheel brakes, side-slip will result, and the back of the vehicle will "come round" unless prevented by the skill of the driver. The extent of the slip can be reduced by releasing the brake and steering to the side towards which the back wheels are moving. When ordinary side-slip takes place on a cambered road, and the back of the vehicle is tending to approach the kerb, the difficulty of arresting the movement is increased for two reasons; first, because the front wheels must be steered towards the kerb, thus reducing the space available for correction

FIG. 4.—*Path of Wheels in* 180° *Side-slip.*

of the error of movement, and secondly, because the camber of the road tends to increase the lateral velocity of the vehicle. The paths taken by the wheels respectively in an ordinary rear-wheel side-slip, on a surface which is level transversely to the direction of movement, are approximately as shown in Fig. 4, in which for the sake of clearness the front wheels are shown narrower in track than the back wheels.

There is, however, another form of side-slip which is much more dreaded by the expert driver, as it is harder to check; this is front-wheel slip.* On greasy asphalt, wet oolite, and damp clayey roads, under normal running conditions the driver may be warned in time by the failure of the vehicle to respond to movement of the steering wheel. With this form of slip, application of the brake,

* Proceedings, Inst. of Automobile Engineers, vol. ii, pages 57-163.

resulting in the transference of some of the load from the back to the front wheels, may produce a sufficient change in the conditions to enable the path of the vehicle to be corrected. It is necessary to consider this aspect of the problem in motor vehicles that are rear-driven. As usually designed the axle loads are approximately equal when the vehicle is stationary; but this condition is changed when the vehicle is running, for the driving torque, corresponding to the speed of the periphery of the road wheels, acts on the back axle and relieves the front axle of part of the static load. Practical recognition of this fact is seen in the racing car, the evolution of which has shown a progressive increase in wheel-base accompanied by forward displacement of the centre of gravity of the car. A racing car of 10 foot wheel-base with a 70 b.h.p. engine, when running at 80 miles per hour, will have a torque at the back axle of about 353 ft.-lb., but the same vehicle if climbing a hill with a gear ratio of 3·5 to 1 (reducing the speed to 23 miles per hour) will have a torque at the back axle of 1,235 ft.-lb., transferring about 1 cwt. from front to back wheel. If, on the other hand, the rear-wheel brake is applied on an ordinary vehicle, the reverse torque so set up may easily be much larger than this; and the resulting change of load conditions on the wheels may therefore increase the insistent load on the front wheels sufficiently to obtain the necessary friction between road and wheel for steering. It is obvious that front-wheel driving implies heavier loading on the front wheels, and involves greater difficulty for the driver in correcting front-wheel side-slip should it occur.

For stoppage under conditions of good road grip the four-wheel brake acting equally on all four wheels is ideal; by the use of compensating gear the braking action can be distributed equally over the four wheels, and for any given speed the car can be stopped in a much shorter distance than with two-wheel braking. When, on the other hand, the surface is greasy, a skilled driver has greater control over a vehicle braked only on the back wheels.

Four-Wheel Driving.

Starley's application of the differential gear to the back axles of

vehicles as a means of compensating for inequalities in diameter or in travel of the wheels requires further extension in the case of the four-wheel drive. When the vehicle is driven mechanically by a single petrol motor, it is not only necessary to provide a differential gear on each axle, but, when these are of the ordinary bevel or spur types, a third differential gear must also be interposed between the two axles to compensate for differences in the mean diameters, and consequently in the revolutions made by the respective pairs of wheels. This introduces a further complication in the problem of driving. In the ordinary two-wheel drive if one driving wheel is held and the other is off the ground, the latter will revolve, other things being equal, at double the speed at which the pair would revolve if both were free; whereas, if with the arrangement of three differentials three wheels are held and one wheel is off the ground, this wheel will revolve at four times the mean speed at which the four would revolve if free or driving normally. Conditions under which the load on any one wheel is so far reduced as to allow of slipping occur frequently on very uneven ground owing to release of spring pressure, and they also occur on ground presenting considerable fluctuations in coefficient of friction. To enable the four-wheel drive vehicle, fitted with the usual bevel or spur wheel types of differentials, to work under these conditions it has been found necessary to fit a differential-lock to the main or central differential on the longitudinal driving shaft connecting the two axle drives.

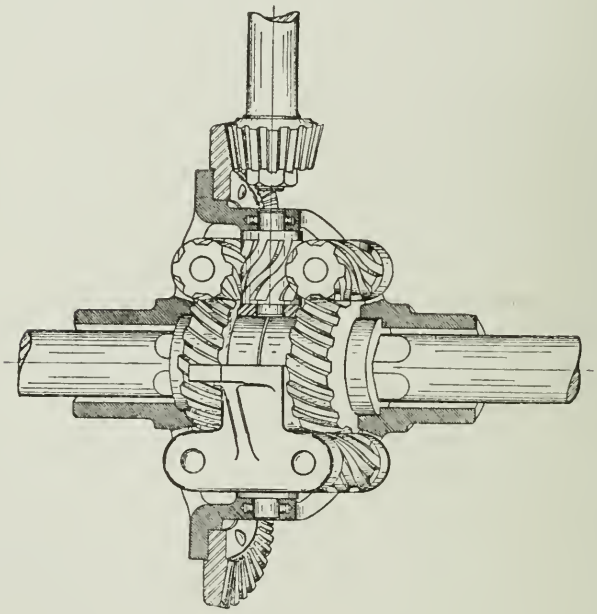
This difficulty is not so serious in vehicles fitted with electric drives, in which it is, of course, possible to fit a separate motor to each wheel. An arrangement of this kind is used in the Couple-gear car, and is shown in Fig. 32, Plate 6.

Automatic Differential Locking Gears.

The problem of power transmission when one wheel is off the ground, or has no hold, as when in a clay-hole or on ice may, however, be solved in another way. The slipping or free-running of one wheel is due to the fact that the ordinary bevel or spur differential gear is perfectly reversible. If one wheel is jacked off

the ground it will revolve at twice the normal speed corresponding to the engine-revolutions; and *vice versa*, if the wheel is turned round by hand the engine will make half the corresponding number of revolutions. An attempt made by Hedgeland, about 1905, to solve this problem proved partially successful;* but a really practical solution appears to have been found in the worm-gear differential.

FIG. 5.—*M. & S. Differential.*



The M. & S. differential, shown in Fig. 5, is of this type.† In this arrangement each axle-end carries a crown worm-wheel of the same hand, each gearing into a worm-pinion carried in

* *See* Historical Note, page 138.

† *See* the Paper on Differential Substitutes by D. D. Ormsby. Transactions of the (American) Society of Automobile Engineers, vol. xi, 1916, Part II, pages 288-299.

the differential-box; the two worm-pinions are geared into an intermediate worm also carried in the differential-box. In practice the arrangement of secondary and intermediate worms is duplicated as shown in the figure. The inclination of the teeth is selected so that the worm-pinion can be driven by the crown worm-wheel, but that the action is not reversible. Hence the gear will

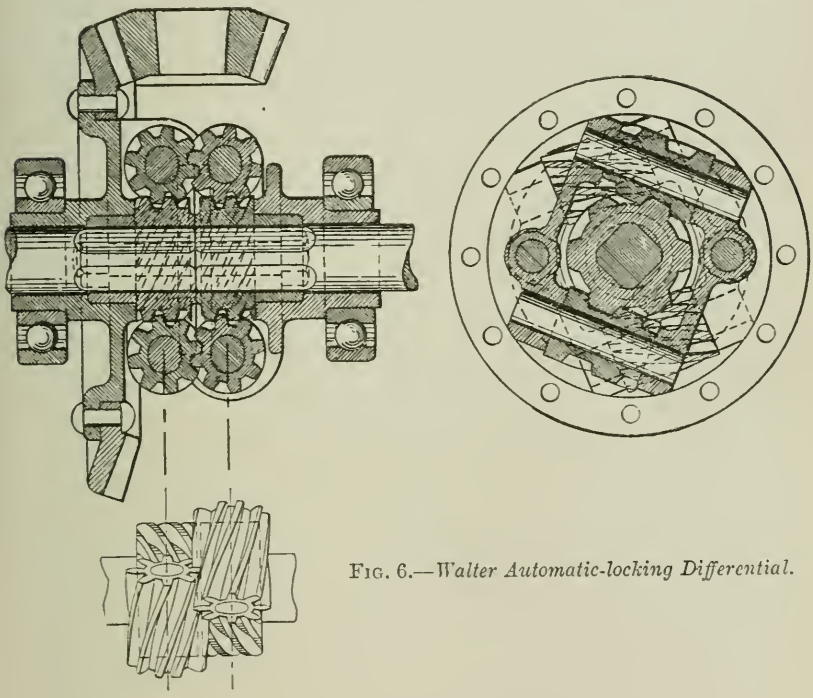


FIG. 6.—*Walter Automatic-locking Differential.*

admit of the road wheels travelling at different speeds if both are in contact with the ground, but if one wheel is off the ground or has no hold, the irreversibility of the drive causes the whole arrangement to behave as though it were a solid axle. This peculiarity, causing the worm form of differential to be known sometimes as the "positive-drive" or "automatic locking

differential," renders unnecessary the central or third differential, with its differential locks, required when differentials of the bevel or spur types are used for four-wheel drives.

The Walter automatic differential lock, Fig. 6 and Fig. 25, Plate 5, is also a worm-gear differential. In this form the half-axles each carry a crown worm-wheel, and as in the M. & S. gear both are of the same hand. Each crown worm-wheel engages with a worm-pinion carried in the differential-box; these worm-pinions being both of the same hand are carried on axes, the one of which is advanced in relation to the other at an angle double that of the inclination of the worm pinion thread to its axis. This arrangement eliminates the intermediate worm-pinion necessary in the M. & S. gear and thus shortens the overall length.

In practice there are two pairs of worm-pinions as shown in Fig. 6. It is claimed that a static lock is ensured between the two axles "because a worm-gear cannot start driving a worm having a 'much' smaller angle of lead," but that once started the driving is performed at high efficiency," * that is to say, there is differential driving of the wheels, but not equal distribution of power to the two wheels. It is also stated that this design is so compact that it can be substituted for the ordinary bevel or mitre gear differential.

In this country the problem of the automatic differential lock has been attacked by Wolseley Motors in a different way. In one example small multiple-plate clutches are arranged in the differential-box at each side so that they are acted upon by the end-thrust of the gears; this end-thrust exists already in the case of bevel or mitre gear differentials, but in the spur form of differential it is obtained by making the satellite pinions (with axes parallel to the differential axis) alternately right- and left-handed worms geared together and gearing respectively with left- and right-handed worm-wheels, of the same tooth inclination, carried on the respective ends

* The word *much* has been inserted by the Author in the description here given, because the context implied it. The conditions for irreversibility are given by Lanchester in his Paper on Worm Gear. Proceedings, Inst. of Automobile Engineers, vol. ii, pages 219 *et seq.*

of the axle-halves; the end-thrust of these worm-wheels acts on the multiple-plate clutches in the same manner as in the bevel or mitre gear differentials.

The possibility that the automatic action may not ensure complete locking of the wheel or wheels is provided for in a modification of the arrangement. In this form the multiple-plate clutch sleeves carrying the thrusting wheels (whether bevel or worm) are provided with collars against which forked levers pivoted to the differential axle casing can be made to press by means of a hand lever acting through appropriate linkwork. The gear thus forms a partial lock under normal conditions and becomes a complete lock when desired.

Another form of differential locking automatically is the Dorr Miller, Fig. 7, Plate 1.* This gear consists of the following parts: a central driving plate, eight steel balls carried in holes in the driving plate, two groove-blocks with axially waved races for the balls, and two friction plates, one on the back of each groove-block, having one face bearing on the groove-block, and the other on the inside of the differential-box. As soon as spinning or skidding starts, the groove-block which tends to move faster also tends to move away from the central driving plates by the action of the balls in the waved grooves. This action causes the outer surfaces of the groove-blocks to bind against the inside surfaces of the friction-plates which in turn tend to bind on the inside of the differential-box, thereby converting the differential temporarily into a solid unit. Under normal conditions it is claimed that the rolling of the balls over the waved grooves permits perfect differential action.

It is the Author's opinion that it is desirable that comparative tests of the various forms of automatic differential-lock should be made by an independent authority, such as the National Physical Laboratory.

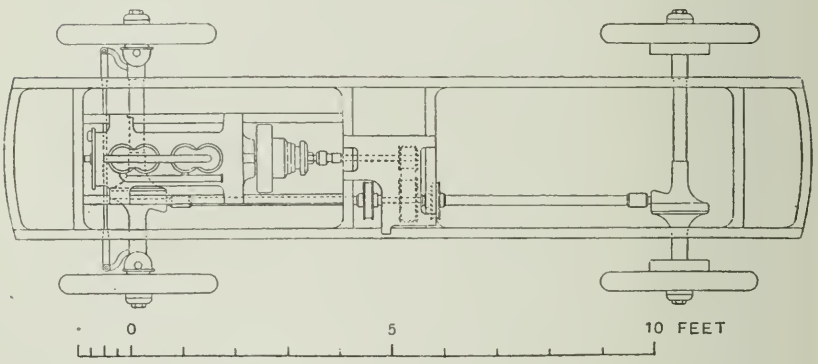
---

* The Author is indebted to Mr. A. A. Remington, M.I.Mech.E., Chief Engineer of the Wolseley Co., for the description of this gear and of the two forms of Wolseley gear.

FOUR-WHEEL DRIVE, FRONT STEERING.

The F.W.D. (Four-Wheel Drive) car of Clintonville, Wis., Fig. 12, Plate 2, is a four-wheel driven car with front steering, and is fitted with hand-operated differential-locks to the central differential, Fig. 10, Plate 1. A skeleton plan of the arrangement of engine and drive is given in Fig. 8, and details of the front-wheel driving and steering arrangements as seen from the front of the vehicle are shown in Fig. 9 (page 67). The driving gear is shown in phantom view in Fig. 11, Plate 1. A dog-clutch is provided for locking the central differential, and making it inoperative as a balance-gear

FIG. 8.—*F.W.D. Chassis; Skeleton Plan.*



between the two axles. With the central differential locked, one or other of the clutches on the short shafts, which transmit power to the front and back wheels respectively, can be disengaged by the corresponding dog-clutch; one of these clutches is shown disengaged on the right of the chain-driven differential in Fig. 11, Plate 1. By these means the vehicle can be converted temporarily into a two-wheel back-drive or front-drive vehicle, as may be best suited to the difficulty requiring the use of the differential-lock. Actually two locking gears are provided, one for each end of the differential, Fig. 10, Plate 1. For continuous work as a two-wheel drive car the lock is engaged which is next to the shaft that is being used

in driving, so as to avoid transmitting the locking action through the teeth of the differential gear. The position in which the differentials are placed out of the centre of the car, Fig. 8 (page 66), is in part constructional, and in part is selected with the object of obtaining greater central ground clearance than would be possible with a central drive. The back-axle drive of this car is of the kind known as the "full floating type," * that is to say, the axle is one in which the wheel-driving, or differential shafts, transmit only torsional effort, and are not subjected to bending stresses either by the weight of the vehicle or by the tractive

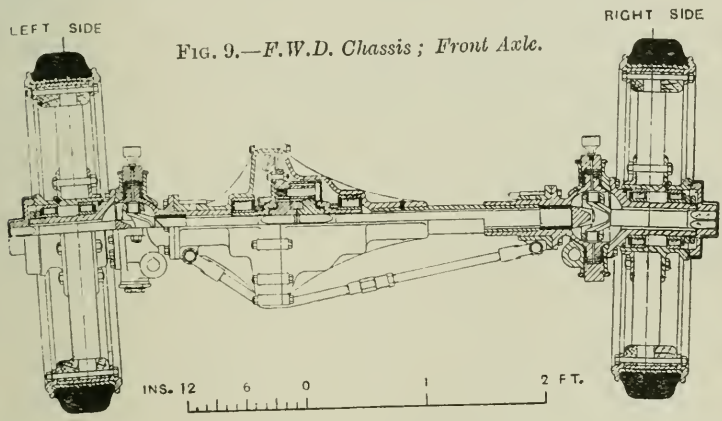


FIG. 9.—*F.W.D. Chassis; Front Axle.*

resistance. The front-axle drive is shown in Fig. 14, Plate 2, and a complete side-tipping wagon in Fig. 13, Plate 2. Examples of wagons at work are shown in Figs. 15 to 17, Plate 3, and an end-tip wagon in Fig. 18, Plate 4.

FOUR-WHEEL DRIVE, FOUR-WHEEL STEERING.

The Super-quad of the Walter Motor Truck Co. of New York, Figs. 23 and 24, Plate 4, is an example of four-wheel drive and four-wheel steering, and is shown in plan and elevation in Fig. 19

* Live Axles for Commercial Vehicles, by G. W. Watson. Proceedings, Inst. of Automobile Engineers, vol. x, pages 165 *et seq.*

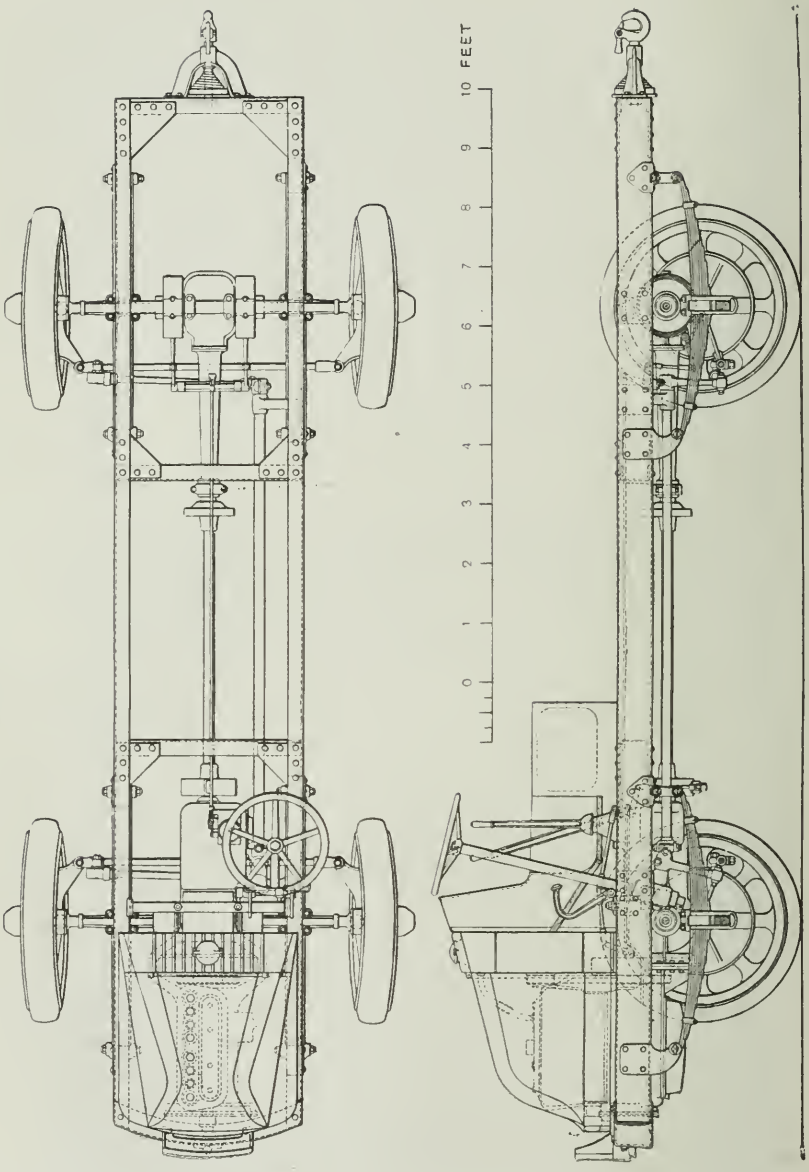


FIG. 19.—*Walter Super-quad; Plan and Elevation.*

FIG. 20.—*Walter Super-quad; Tractor.*

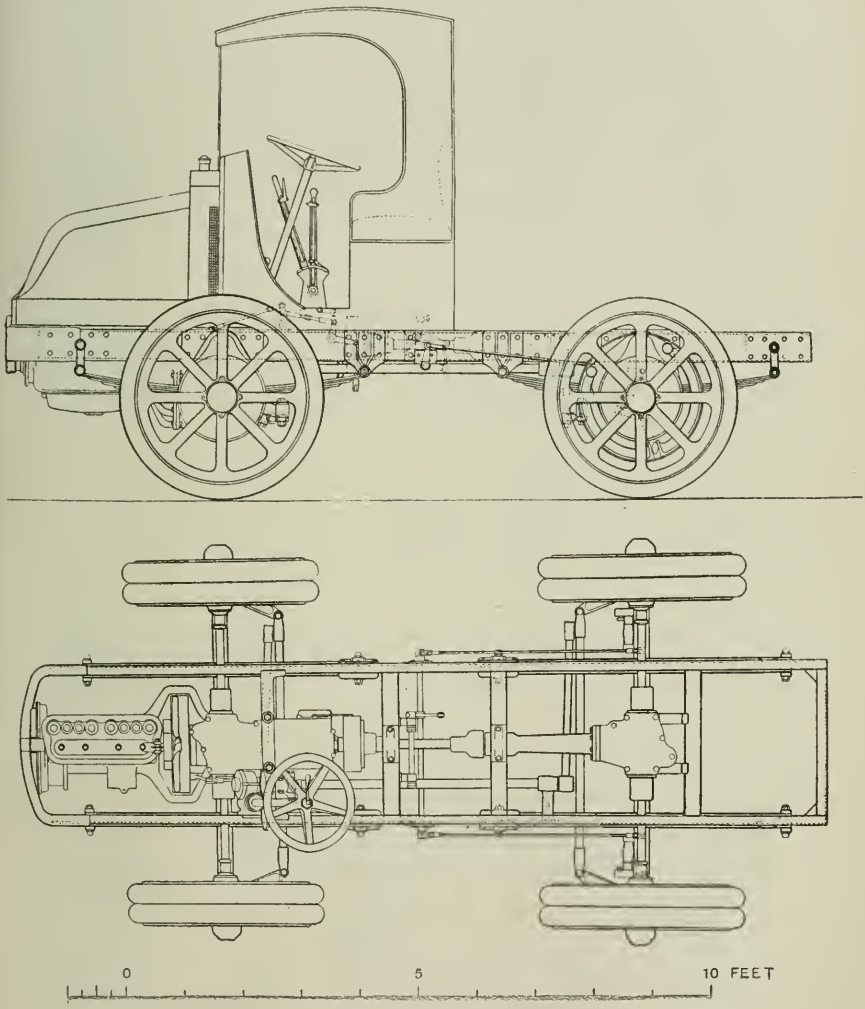


FIG. 21.—*Walter Super-quad. Transmission.*

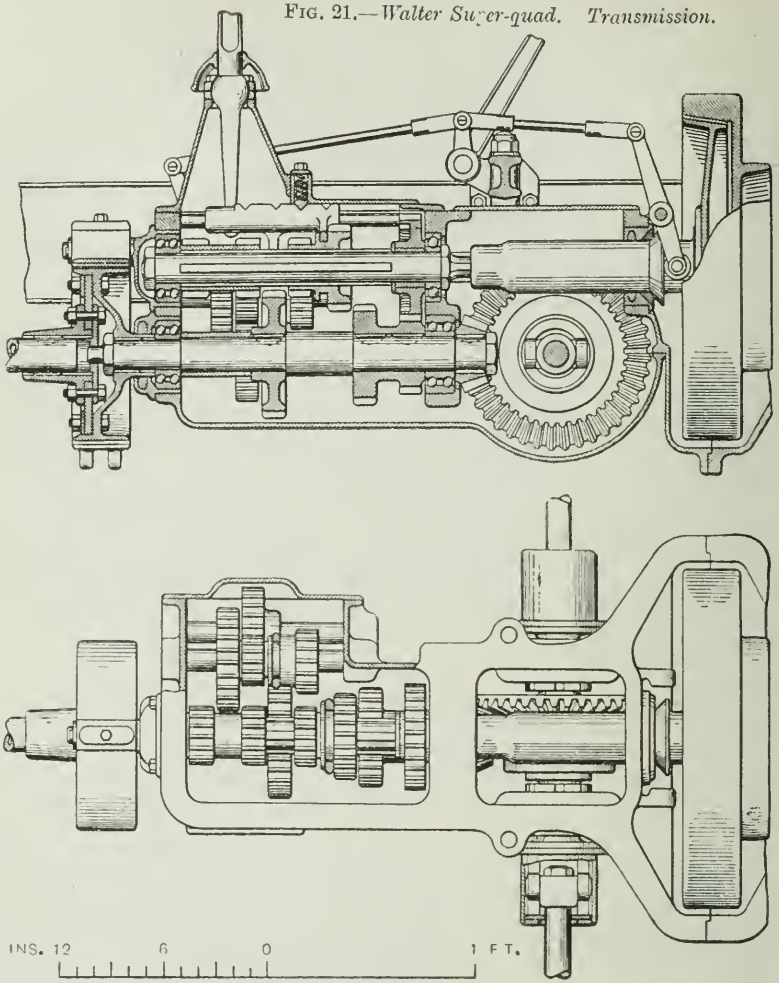
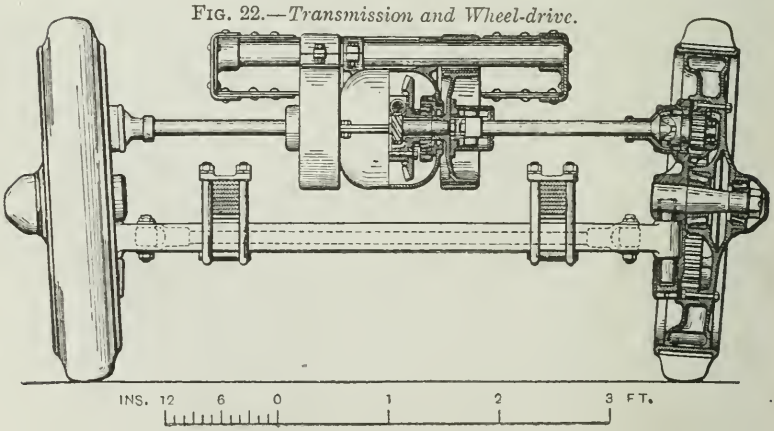


FIG. 22.—*Transmission and Wheel-drive.*



(page 68); a semi-tractor is shown in plan and elevation in Fig. 20. The transmission gear is shown in elevation and plan in Fig. 21, the front-wheel differential shafts with the cardan joints for the short driving shafts to the front wheels being shown in section and outside views. The method of driving the wheels by short articulated shafts is shown in Fig. 22.

Each axle is fitted with an automatic locking differential of the Walter type, which remains automatically locked for normal running, but becomes unlocked when necessary, for example, in turning the car. The two Walter automatic-locking differential gears, Fig. 25, Plate 5, are, moreover, sufficient; the third differential gear on the main shaft, necessary in the case of ordinary differentials, is not required with this device, as either or both wheels on the axle which tends to overrun the other will become unlocked automatically, and will lock again as soon as the distribution of velocity becomes normal.

The vehicle is fitted with a pedal-operated transmission brake and a hand-lever operated back-wheel brake, both of which, owing to the fact that the main differential is either in gear or is locked, also act on all four wheels.

THE JEFFERY QUAD shown in Figs. 26 and 27, Plate 5, is a four-wheel driving and four-wheel steering vehicle, better known in this country than the Walter. This vehicle is fitted with the M. & S. locking differential on each axle, Fig. 5 (page 62).

Some of the forms of body adapted to this chassis are shown in Fig. 28 (page 72), and comprise two forms of hoist or tip bodies and two forms of special bodies for the transport of liquids, etc.

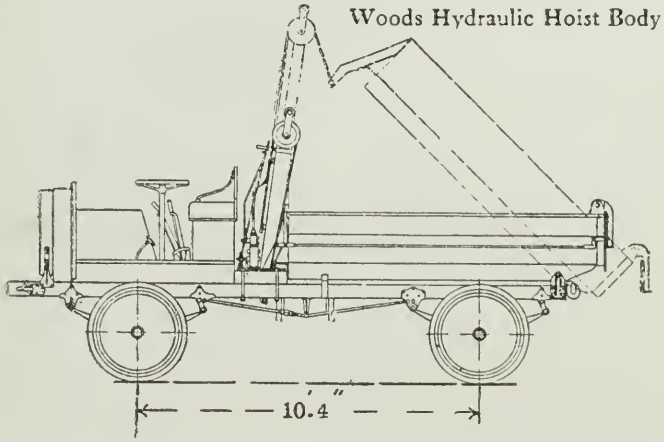
FOUR-WHEEL INDEPENDENT DRIVE WITH FOUR-WHEEL STEERING.

The Couple-gear electric truck, Fig. 29 (page 73), and also the petrol-electric truck, Fig. 30 (page 74), of the Couple-gear Freight Wheel Co., of Grand Rapids, Mich., afford examples of four-wheel independent drive with four-wheel steering.

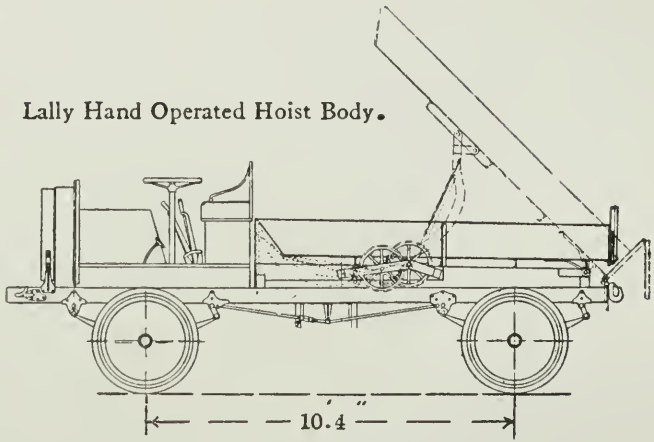
The battery-driven car is shown in elevation, front elevation and plan in Fig. 29. The wheel is of peculiar construction, having two large-diameter bevel wheels enclosing the motor, which is placed out of square with the axle to a sufficient extent to allow

FIG. 28.—*Jeffery Quad; Applications.*

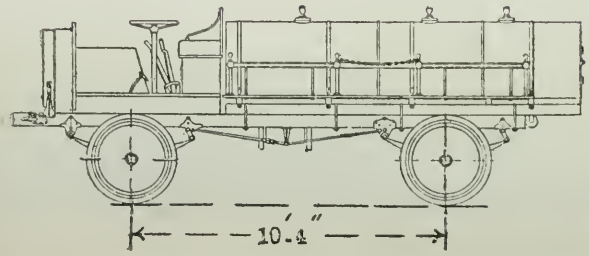
Woods Hydraulic Hoist Body.



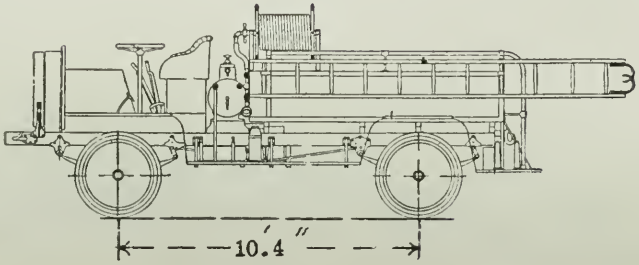
Lally Hand Operated Hoist Body.



Oil Tank Body.

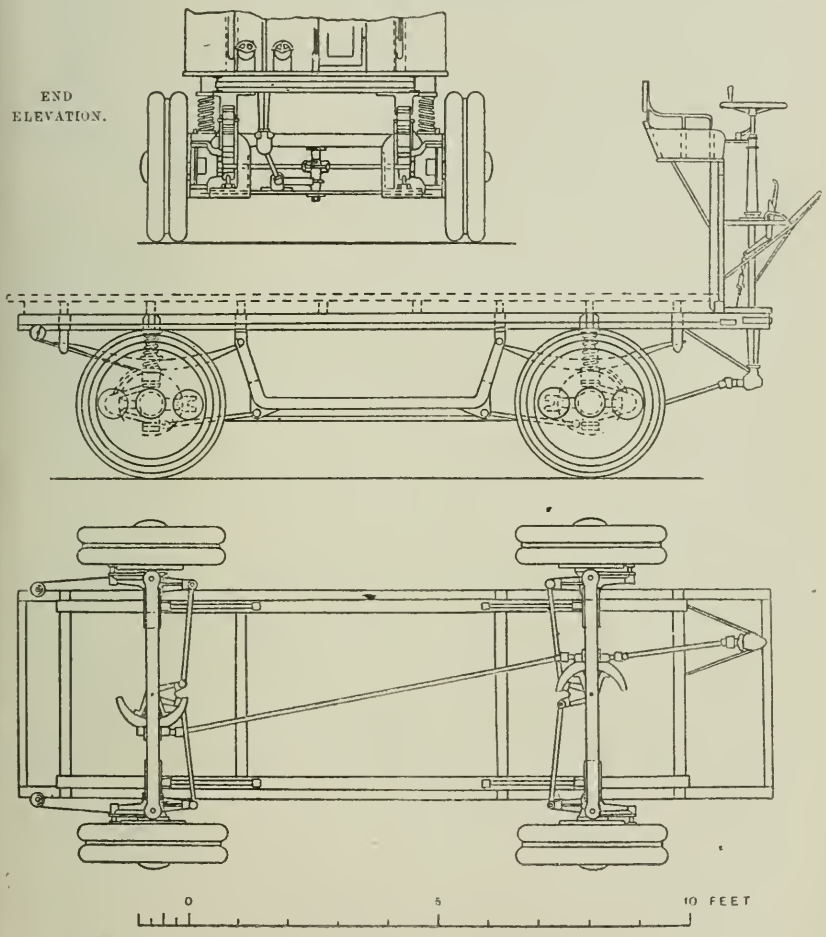


Combination Chemical and Hose Truck Body.



both ends of the motor shaft to carry a driving bevel pinion. One of these pinions gears with the outer half of the wheel and the

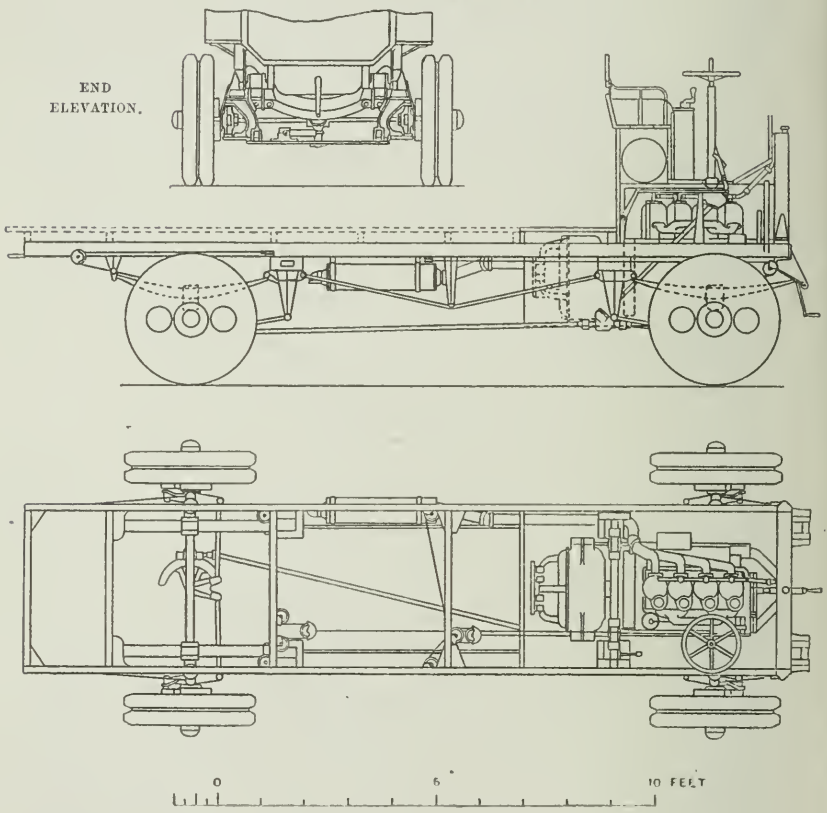
FIG. 29.—*Couple-gear; Electric Truck.*



other with the inner half, so that the load on the motor shaft is balanced, a result further ensured by the introduction of an "evener" or compensating gear; the arrangement of the wheel

parts is shown in Figs. 31 and 32, Plate 6. A channel frame carrying twin solid rubber tyres is secured over the two bevel-carrying disks forming the wheel. The gear reduction from motor to wheel is 25 to 1; the relation between tractive effort and speed

FIG. 30.—*Couple-gear; Petrol-electric Truck.*



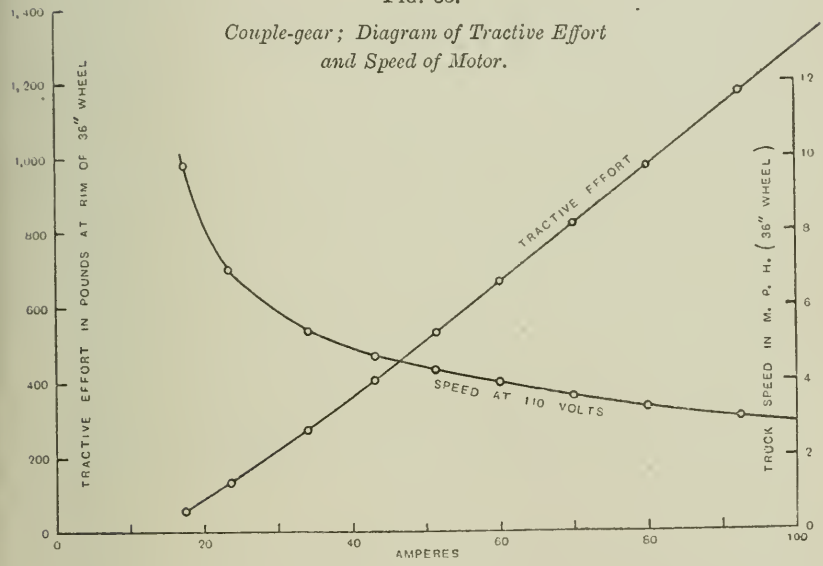
is given in Fig. 33. The motor is carried on a short hollow stub-axle keyed to a taper seat in the steering knuckle and secured by a nut; the wires are led to the motor through the stub-axle pin. The wheels run on roller bearings and are fitted with hand holes

with removable doors to give access to the motors. There is one brake of the contracting type to each wheel, and also an electric emergency brake.

To enable the vehicle to be driven over roads which present uneven surface or very unequal resistance to traction a special form of control is arranged. Current is supplied to the motors of the four wheels through a controller of the street-car type modified to suit the conditions. This controller has five contact points, two of

FIG. 33.

Couple-gear; Diagram of Tractive Effort and Speed of Motor.



which (the third and fifth in the battery car, and the fourth and fifth in the petrol-electric car) are arranged for what the makers term "parallel speeds," the motors being put in parallel when these contacts are made; thus, if one wheel slips it has no effect on the other three, or if two wheels slip there is no effect on the other two. The other three contacts are for what the makers term "building-up speeds"; on these points a sort of differential action is provided between the two groups of wheels taken diagonally on the car. The right front wheel and left back wheel form one group,

and the left front and right back form the other group. When running on the third building-up speed a differential action occurs between the wheels of these groups, so that if one wheel of the group slips, its fellow will be left without power. If under these circumstances the slipping continues, and the driver of the vehicle moves the controller forward to the next contact, all the wheels are then put to work independently of each other.

It is stated that on a dry gravel road a tractive effort equal to 60 per cent. of the total weight of the vehicle can be obtained before the wheels begin to slip. This figure depends, of course, on the character of the road surface.

The accumulator-driven type of tractor is only recommended in cases where charging facilities are obtainable, and the total daily mileage does not exceed 40 miles. The petrol-electric vehicle is shown in elevation, front elevation and plan in Fig. 30 (page 74), and the power plant in Fig. 35, Plate 7. These vehicles are not only used as ordinary lorries, but in many instances are adapted with a pivotal carriage to take the front end of a trailer which may be a goods wagon, fire-escape, or electric-tramway tower wagon. In this application the vehicle is sometimes known as a semi-tractor. The Couple-gear driving system is also applied to two-wheel drive vehicles such as fire-engines. Fire-escapes are dealt with by two methods; either as a very long wheel-base vehicle, Fig. 36, Plate 7, or on the semi-tractor principle with a long trailing wagon.

Applications of Four-Wheel Drive to Bad Roads or Land.

In the mining and agricultural districts of North America vehicles are required to negotiate long stretches of sand or mud. They are required to work on desert land, through sagebrush and among sand dunes, under such conditions as are illustrated by the views of F. W. D. vehicles given in Figs. 15 and 16, Plate 3, and they may even be used to haul trains of tip-wagons on a light railway straddled by the tractor, Fig. 17, Plate 3. An end-tip wagon with hydraulic tipping gear is shown in Fig. 18, Plate 4.

The limitations in all these cases are defined by the engine

power, transmission efficiency,* insistent load, wheel diameter, tyre width, weight of vehicle, and, when a trailer is hauled, the drawbar pull. There is no satisfactory method at present known for estimating the resistance presented by land, sand or mud, so soft that the wheels can sink to a depth of several inches, though it is known that the resistance under such conditions may be as much as 15 to 20 per cent of the load. The illustrations must therefore be taken as the best method of affording some idea of the work that can be performed by four-wheel driven vehicles.

Comparative figures for the different types of vehicle, their horse-power, speeds, load, weight, wheel-base, track-width, turning radius, and overall dimensions are given in Table 1 (pages 144–5).

Conclusions.

For the transport of goods over bad roads on gradients, varying from 1 in 15 on roads in which the tyres sink 2 to 3 inches in depth to 1 in 5 on hard roads with bad surface, and for speeds varying from 1·5 mile per hour on grades to 12 miles per hour on fairly level roads, the four-wheel drive tractor has great advantages over the ordinary two-wheel drive tractor.

In the Author's opinion it may be expected to rank as an important factor in the development of districts overseas not far removed from rail-head, but having only primitive roads.

PART II.

Chain-Track Tractors.

The invention of the endless track or self-laying railway dates to nearly a century and a half ago. The first mention of a scheme analogous to that now adopted in so many forms of tractors is the

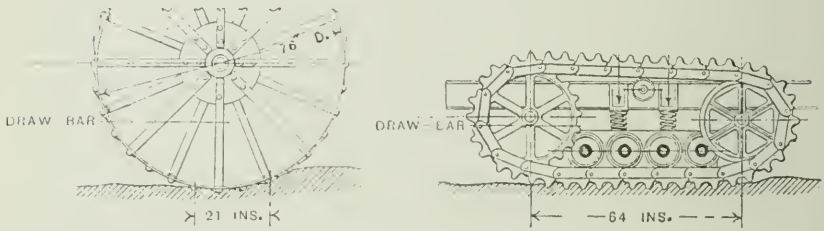
---

* The efficiency of gear-box and bevel transmission does not appear to have been investigated thoroughly. The Author believes that in vehicles of the types described it amounts to about 85 per cent of the engine b.h.p.; Proceedings Inst. of Automobile Engineers, vol. iii, pages 357 *et seq.*

British invention of Richard Lovell Edgeworth (15th February 1770) for a "portable railway" or artificial road to move along with any carriage to which it is applied. Although no drawings can be traced of the invention, the description given is remarkably clear and precise; in fact, almost unaltered, it applies to the greater number of chain-track tractors of to-day.*

The Motor Car Acts of 1896 and 1903, while affecting the restrictions on light locomotives, had little if any direct influence on the development of chain-track tractors. This type of vehicle owes its development to the very great difficulties presented to wheeled tractors by bad surfaces of road or land. The worst conditions are snow, ice, sand, clay, and marsh. Of these snow and marsh

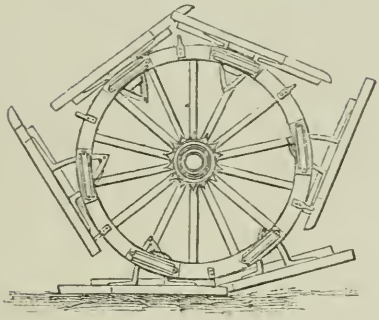
FIG. 37.—*Wheel and Chain-track Compared.*



have had most often to be faced, the former for the haulage of lumber in winter over snow and ice tracks in forest country, and the latter for the haulage of gang-ploughs through the marshy deltas of California and in the swampy country of Illinois and Wisconsin. The necessity for travelling over various kinds of land in moving from place to place has demonstrated the capacity of these vehicles for haulage across alkali and other deserts as well as over clay. To enable chain-track tractors to run on soft or swampy land the insistent weight has been reduced much below that imposed by a horse, which, carried on two feet as in walking, may exert a pressure on the ground of from 20 to 25 lb. per square inch. In fact many of these machines can be run safely over marsh in which a man would sink to his waist. The pressure

* *See* Historical Note, page 136.

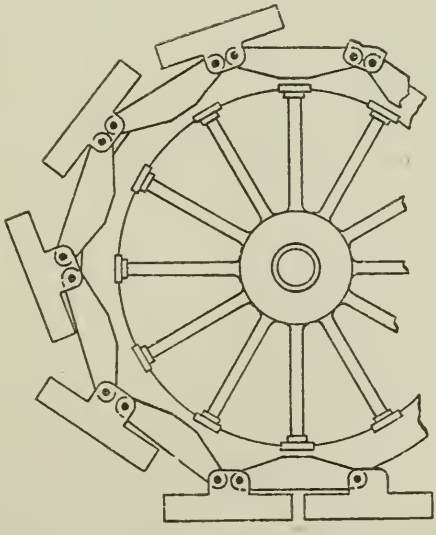
FIG. 38.—*Boydell Girdle.**



exerted by a man when standing on the sole of one boot varies considerably, but may be taken as from 6 to 7 lb. per square inch. Some of the chain-track tractors designed for soft ground have an insistent load of less than 4 lb. per square inch, while in others,

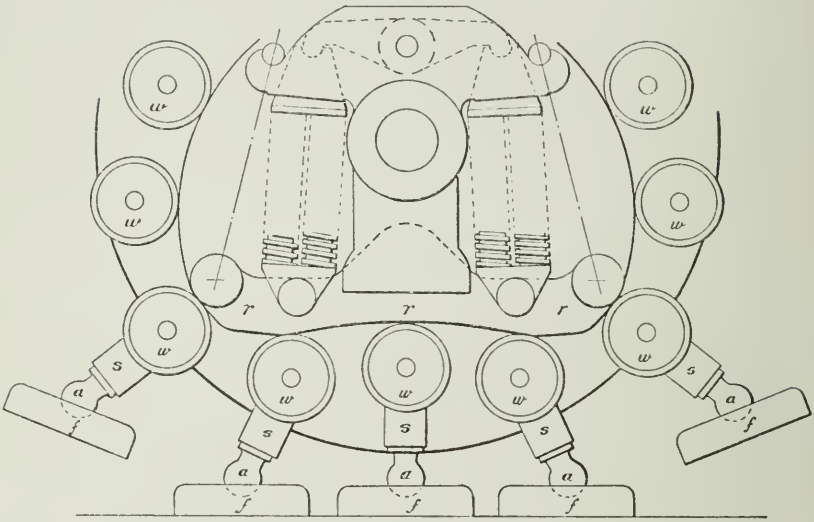
FIG. 39.
Heavy Transport Girdle.

1914.
6 ft. diameter
over plates.



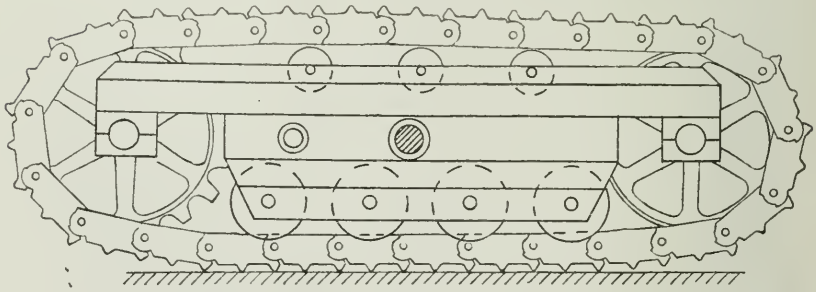
* From "Steam on Common Roads," 1860.

FIG. 40.—*Pedrail; Early Form* (Diplock).



specially designed for swampy country and fitted with tracks of abnormal width, this figure falls as low as 1·8 lb. per square inch. The difference between wheel loading and chain-track loading of soft ground is shown in Fig. 37 (page 78).

FIG. 41.—*Supporting Wheels with Axes fixed Relatively to Truck-frames* (Creeping-Grip).



CLASSIFICATION OF CHAIN-TRACK TRACTORS.

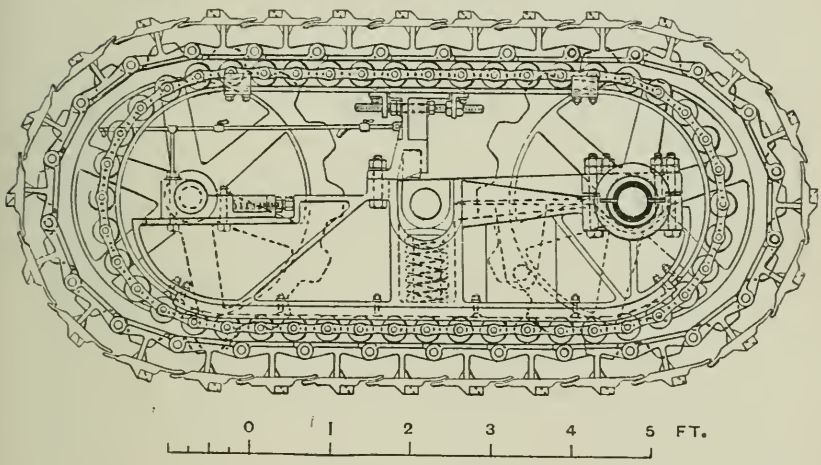
The various track systems may be classified as follows :—

(*a*) Feet or sections laid by a wheel; the girdle form, of which Boydell's tractor, Fig. 38, the ordinary girdle, Fig. 39, and the early Pedrail,* Fig. 40, are examples.

(*b*) Chain-track supporting wheels with axes fixed relatively to the truck-frame by which they are carried; examples of this are the Caterpillar (Holt), Fig. 47 (page 83).

FIG. 42.

Chain-track with Secondary Chain of Travelling Rollers (Centiped).



Creeping-Grip (Bullock), Fig. 41, Tracklayer (C. L. Best), Clayton, Strait, Burford-Cleveland, and others.

(*c*) Chain-track supporting through secondary chains of travelling rollers arranged as intermediate chains between the truck or sledge, and the track- or lag-chain; examples of this are the Log-Hauler (Phœnix) steam tractor for snow and ice, Fig. 42, also Fig. 43, Plate 8, the Centiped (Phœnix) petrol tractor for soft ground,

* Proceedings, I.Mech.E., 1910, pages 1561–6.

FIG. 45.—*Modern Pedrail; Foot and Rail* (Diplock).

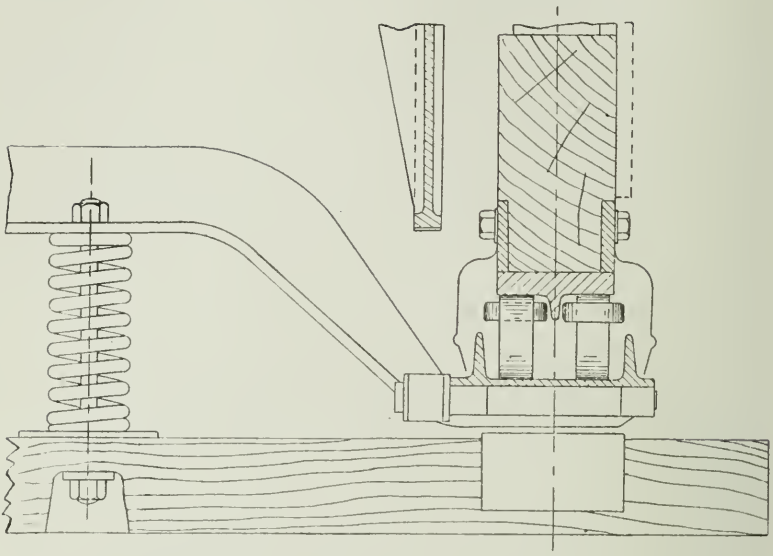
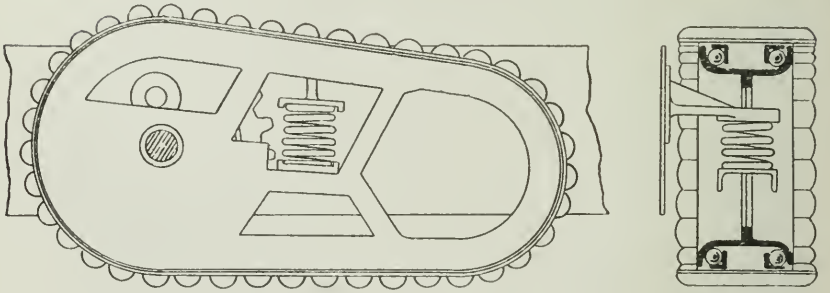


Fig. 70, Plate 12, the Allis-Chalmers, Fig. 73 (page 105), and the modern form of Pedrail (Diplock) Fig. 54 (page 95).

(*d*) Chain-track supporting by rows of travelling balls, as in the Ball-Tread (Yuba) tractor, Fig. 46.

Apart from the girdle, sometimes fitted to hauled vehicles, there

FIG. 46.—*Chain-track with Rows of Travelling Balls* (Yuba).

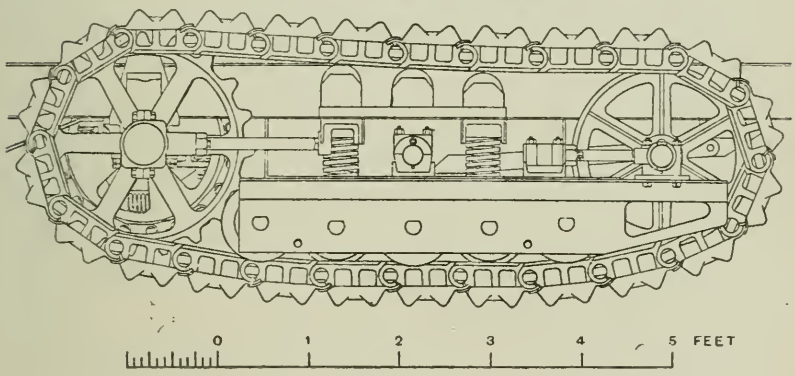


is no modern representative of extended application of tractors of class *a* known to the Author.

The chain-track tractors that are constructed and used in the largest numbers, both as to makes and output, are those with wheels revolving on axes fixed to one or more truck-frames for each track, class *b*.

It appears that chain-track tractors for the haulage of lumber were made and used commercially in the United States as early as 1904, and some of these early tractors are stated to have been still at work last year; these vehicles are fitted with the intermediate roller chains of class *c*.

FIG. 47.—*Chain-track partly Spring-Supporting* (Caterpillar).
(For complete view, *see* Fig. 86, page 106.)



Tractors in which the load is transferred from the chain to the track-frame by rows of travelling balls, class *d*, are represented at present, so far as the Author is aware, by the single example of the Ball-Tread (Yuba).

METHODS OF SPRINGING.

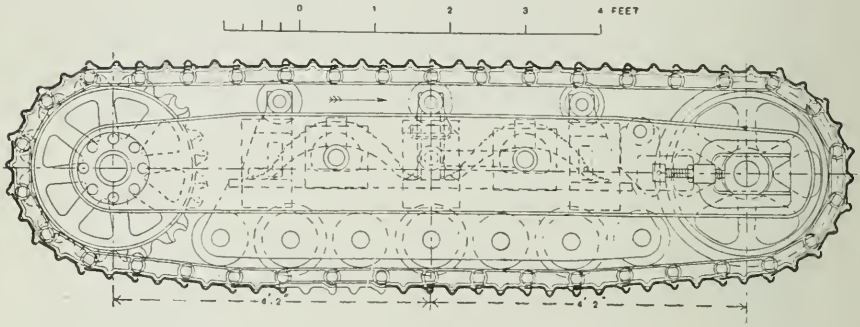
Four distinct systems of springing have been tried or are in use:—

(*e*) Foot springs; in this method the springs are interposed between the actual foot and the carrying portion, Fig. 45; examples are the old and new forms of Pedrail (Diplock), Fig. 40 (page 80) and Fig. 44, Plate 8.

(*f*) Track wholly spring supported, the axle of the track-frame being carried on springs; Centiped (Phœnix) and Allis-Chalmers, Fig. 73 (page 105).

FIG. 48.—*Chain-track totally Spring-Supporting over Effective Length* (Clayton).

(For enlarged Details, *see* Fig. 95, page 111.)

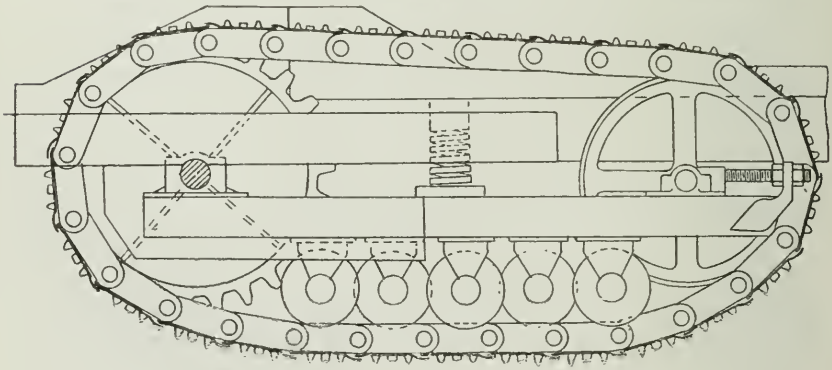


(*g*) Track partly spring supported: Caterpillar (Holt), Fig. 47, and Clayton tractor (totally over effective bearing portion), Fig. 48.

(*h*) Track pivotally sprung; Tracklayer (Best), Fig. 49, Strait tractor (Killen-Strait), Fig. 50, and Ball-Tread (Yuba), Fig. 46 (page 82).

FIG. 49.

Chain-track Frame with Pivotal-springing about Back Axle (Tracklayer).



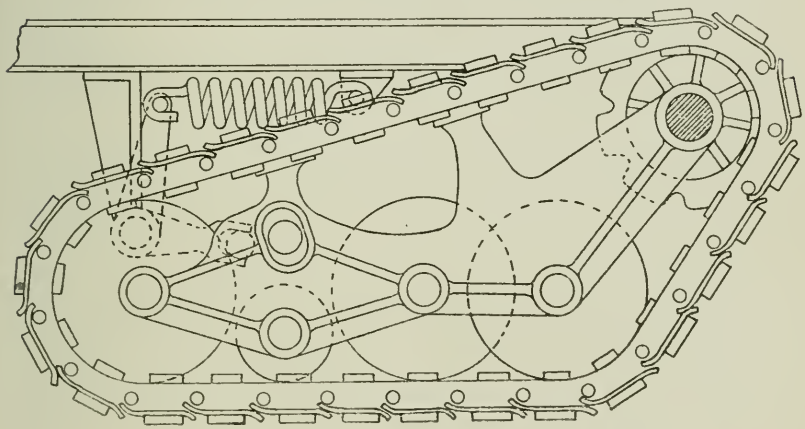
Owing to many constructional difficulties, direct springing of the feet, class *e*, has not yet taken a prominent place among commercial chain-track tractors.

The methods of track-springing are intimately associated with those adopted for ensuring equable load distribution on the chain.

The method of supporting the vehicle on springs carried on the track-axle, class *f*, requires either a chain or a cardan drive to permit driving when the springs are unequally loaded, as when crossing ditches or running on side-lying ground.

FIG. 50.

Chain-track Frame with Pivotal springing about End Bearing (Strait).



In some vehicles of class *g* the whole of the effective portion of the track is capable of vertical movement, as in the Clayton tractor, Fig. 48, in which a link connects the single truck-frame to the track-frame. In others the truck is in one or more parts controlled by linkwork from the back or driving-sprocket axle, a practice followed successfully by the Caterpillar (Holt), Fig. 47.

In other tractors having chain-driven sprockets the whole of the track-frame is capable of pivoting about a central axle, an arrangement which is adopted in the Creeping-Grip tractor, Fig. 41; or the track-frame may be pivoted and sprung about the axle of the

driving sprocket, as in the Tracklayer (Best), Fig. 49, and the Strait tractor (Killen-Strait), Fig. 50. These two arrangements, though very different in appearance, are both equivalent to partial springing of the track, class *h*.

Truck-Frames and Track-Frame Connexions.

The various methods adopted for distributing the load of the tractor over the chain-track elements may be classified as follows:—

(*j*) Truck-frame and track-frame identical; this arrangement is adopted in the modern form of Pedrail, in the Strait, Fig. 50, Log-Hauler, Fig. 42, Centiped, Allis-Chalmers, Fig. 73, and Ball-Tread, Fig. 46.

(*k*) Truck-frame integral with track-frame; this form of construction, which very closely resembles the preceding, is adopted by the Tracklayer, Fig. 49, and Creeping-Grip, Fig. 41.

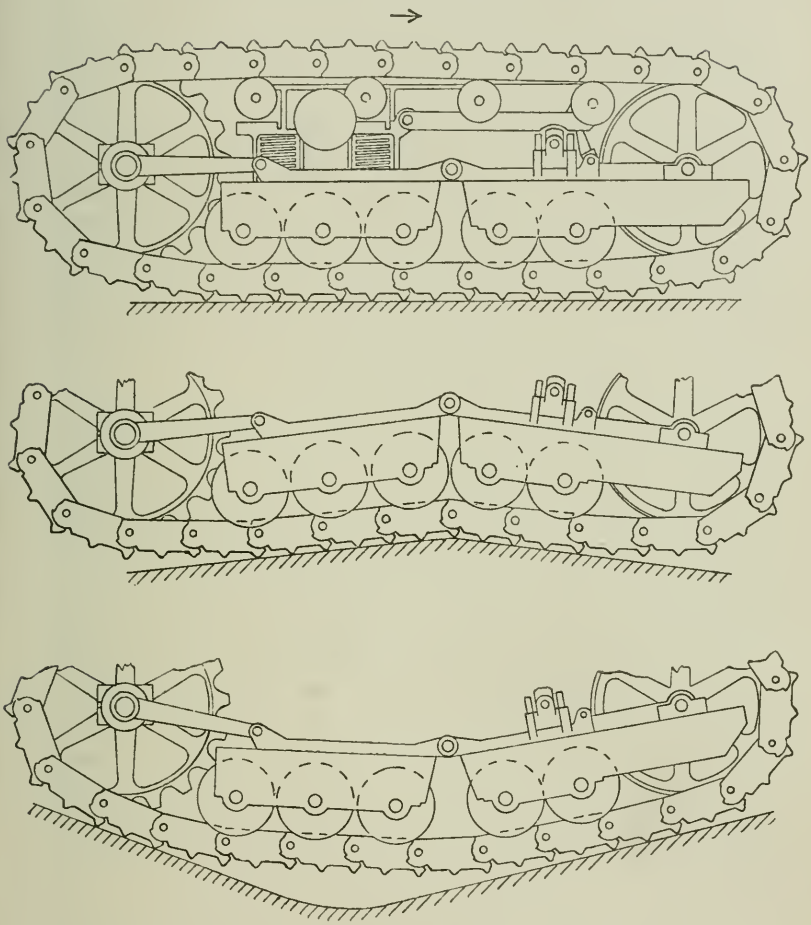
(*l*) Truck-frame in one piece connected by a link or guides to the track-frame; this method is used in the Clayton tractor, Fig. 48.

(*m*) Multiple truck-frame articulated and connected by links to the track-frame; this is adopted in the lower powered Caterpillar, Fig. 51, and enables the load on the chain-track to be distributed over irregular surfaces to which the chain-track and truck-frames can adapt themselves under the action of the springs.

When the track-frame is pivoted to the main framing, the whole length of supporting-surface of the chain-track is capable of adapting itself to long undulations or irregularities, Fig. 69, Plate 12; this arrangement is therefore very suitable for use on ordinary ground, snow, ice, sand or marsh. The articulated truck-frame, on the other hand, permits a more even distribution of load over the chain-track elements when passing over small irregularities such as stones, rocks, railway ties, rails, etc., and for this reason is better adapted for haulage from rail-head into country in which rock crops out.

FIG. 51.—*Multiple-articulated Truck-frame* (Caterpillar).

(For complete view, *see* Fig. 91, page 110.)



STEERING.

The arrangements adopted for steering vary considerably. In several models, of which the Centiped and Creeping-Grip are examples, there are steering wheels with steering of the ordinary Ackermann type; in others the practice is to use a single steering

wheel, as in the Caterpillar (Holt 75 h.p.), Clayton, and Ball-Tread (Yuba). The steering wheel of the Clayton is fitted with an elevating gear, so that it can be raised out of action for turning small circles. In the Strait there is a small steering chain-track; in some of the lower-powered tractors—Caterpillar (Holt 45 h.p. and 18 h.p.), Baby Creeping-Grip (16 h.p.) and F. C. Austin (35 h.p. and 15 h.p.)—the tractor is carried entirely on the two tracks, and steering is effected by releasing the clutch on the inside of the curve to be taken, and driving only on the outside of the curve. In the Burford-Cleveland a brake is applied to one side and the other is driven at increased speed through the differential gear. With some tractors, the Ball-Tread (Yuba) for example, it is possible to turn the machine about its own axis by reversing the driving direction of one of the chain-tracks.

It is obvious that there are four methods available for securing steering of tractors carried on two chain-tracks only; one by the use of the clutches alone; another by supplementing the clutch action by that of a brake acting on the appropriate side; a third by the use of the brake on one side and the action of a differential gear; and the operation of an independent reversing gear to each track gives a fourth method. In the majority of the designs under consideration it is possible to turn the machine in a circle of about 15 to 20 feet radius, and in some of the small tractors the turning circle is only 6 feet radius.

In the Log-Hauler (Phœnix) steam-driven tractor for use on snow and ice runners are fitted for steering, Fig. 59, Plate 9; these can also be arranged with some of the other types described when required to work under winter conditions.

Driving Gear.

The drive of some tractors is fitted with a differential gear; this is usual where there is front-wheel steering, as in the Creeping-Grip or Centiped (Phœnix). In those machines in which steering is effected by declutching one or other of the tracks it is not usual to fit a differential; where, however, the steering is effected or assisted by independent clutching or braking of the tracks, as in the

Clayton tractor and in the Burford-Cleveland, a differential gear is fitted to the main drive between the tracks.

The driving gear generally comprises a main clutch and a change-gear box of somewhat similar pattern to that used on motor lorries or trucks. The number of speeds fitted varies. In one instance, the Allis-Chalmers, there are four forward speeds and a reverse; in a few tractors three forward speeds and a reverse are fitted; two forward speeds and a reverse are more usual; very rarely, as in the high-power Caterpillar (Holt, 120 h.p.), only a single forward speed and reverse is ordinarily fitted, the two-speed gear being an alternative arrangement.

Chain-Tracks.

The design of the chain-track itself is one of the most important factors of the success or failure of the tractor. The chain-track is usually driven by a sprocket at the back end, and passes round an idler at the front carried on the track-frame and engaging only laterally with the chain-track by a central flange or flanges; the idler axle is usually fitted with an adjustment for taking up wear of the chain-track. It will be noted from the cross-sections shown that the width of the track is greater than the width of bearing for the rollers, and any hard object, rock or rail, encountered by the chain may therefore tend to load it unequally, and subject it to torsional stress. Furthermore, if the chain-track passes over a hard and narrow object, such as a railway rail, this will tend to produce reverse curvature in any unsupported portion of the chain. This is particularly the case where the chain has a short free length between the leading idler-wheel and the first pair of carrying rollers. Realization and over-estimation of these difficulties were probably responsible for the early designs of chains made in this country.* The links were so arranged that the connecting-pins were raised several inches from the ground, and the blocks, of which the chain-track was composed, were so made as to butt against each other when the chain-track was in the position of minimum

* *See* Historical Note, page 136.

curvature. In this way the bearing portion of the chain-track formed an inverted arch, which was supported at portions of its length by the rollers, and depended on contact between the links for carrying the load on intermediate portions of the chain, as shown in Fig. 52. In order to reduce the stresses still further, and to relieve the chain-pins of the heavy load to which they would otherwise be subjected, interlocking extensions above the pins were formed on the chain links. Unfortunately this method of carrying the load resulted in the introduction of new and greater difficulties, generally known as nut-cracker action. If the track worked only on sand or mud, or even on pure clay, there would be no difficulty; but where there is a combination of stones and clay or when, in crossing gravel or roads, any hard object can be picked up by the track and get between the bearing faces of the links, the stresses so caused become excessive and the track may even become jammed. This result can be caused also by pieces of fencing wire or scrap iron such as may occasionally be picked up on a farm. In the forms of chain-track now commonly used the pin centres are brought as close to the ground level as possible, and the chain-plates are so formed as to shield the opening between the track-plates over the working range, as will be seen from Figs. 89 and 95 (pages 108 and 111).

The second source of trouble to which chain-tracks are subject is that of stretching due to wear. This lengthens the pitch of the chain and necessitates fitting an adjusting gear to take up the slack; it also tends to cause riding on the driving sprocket. As it is usual to pitch the chain-pins so widely that they will engage with alternate teeth of the driving wheel, when cut as an ordinary sprocket, this wheel should have an odd number of teeth in order to distribute the wear uniformly over the whole of the teeth.

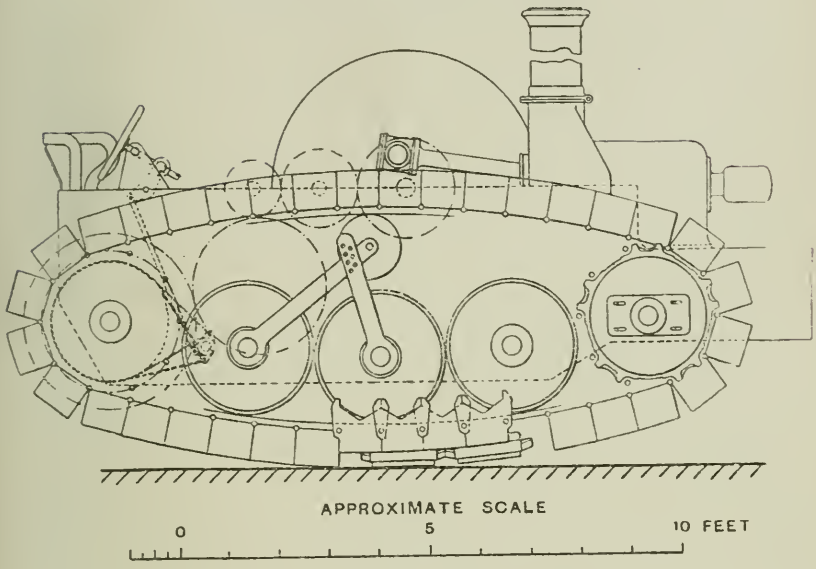
The chain-track links have three functions to perform:—

(1) Carrying the load.

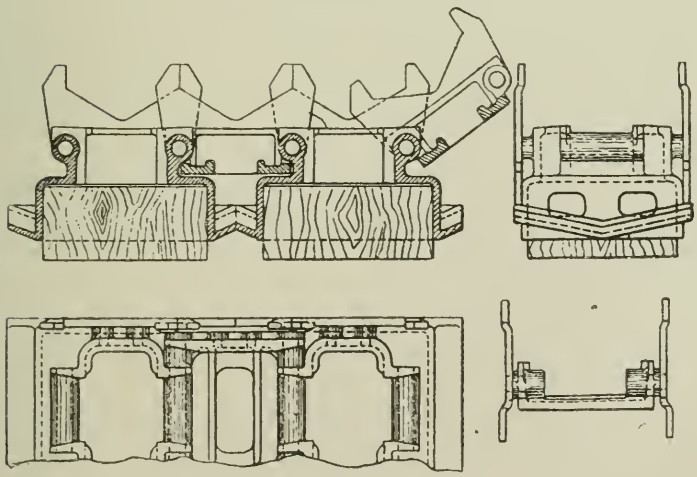
(2) Affording the necessary resistance for traction by engaging with the ground surface, and

(3) Providing the gearing pin, or its equivalent in tooth form, to engage with the driving sprocket.

FIG. 52.—*Roberts Tractor; Side View.*
Illustrating Nut-cracker Action. 1904.



Detail of Chain-track; Section.



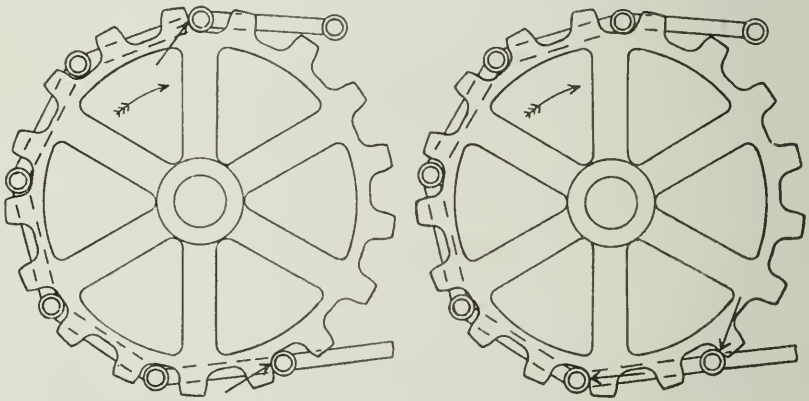
Plan.

The first condition involves a machined surface, preferably hardened, for the carrying rollers to bear on. The second condition necessitates an irregular outline of the lower surface of the link, so that it can gear with the ground surface as a large pinion would gear into a rack; hence the form of shoe must approximate to a ribbed section, and is usually of pressed steel. The third condition requires that the pin-joints or gear faces shall be machined accurately enough to work smoothly with the driving sprocket without risk of riding on its teeth. These three conditions, coupled with the proximity of the connecting pin to the ground,

FIG. 53.—*Sprocket Design to Allow for Wear of Chain* (Hans Renold).

New—
Chain pitch less than wheel pitch.

Worn—
Chain pitch equal to wheel pitch.



have limited the best designs to built-up forms of construction in which the actual link is a machined steel-casting riveted to a pressed steel sole-plate. The conditions of running require that this plate shall be of such form as to clear the end of the next plate throughout the range of inclination to which the links are subjected, and that over the same range there shall be no opening between the plates, in which nut-cracker action can take place (compare Figs. 48 and 52). The troubles due to stretching can be forestalled, as was shown by Hans Renold about twenty-five years ago, by making the pitch of the driving-wheel large in the first

instance, so that the chain-track is driven, at the beginning of its life, from a tooth nearly opposite that which is entering into engagement with it, Fig. 53. By these means a fairly long life can be assured to the chain, provided it is not overloaded, and that efficient lubrication is maintained. The usual method is to supply a large amount of low-grade oil to the inside of the chain; an oil drip so fitted to the side chains of certain early pattern motor-cars (1900–1902), which ran under almost identical conditions of mud and dust, has proved almost as efficient in preserving the chains as frequent removal, washing in paraffin, drying, and soaking in a bath of warm tallow and plumbago. Cheap oil used lavishly appears, in fact, to keep the tracks from cutting or seizing even under very bad conditions. In the Tracklayer (Best) a different method of providing against wear is adopted, the pin being made of rocker form, Fig. 55, Plate 8.

Another matter that affects the design of the whole chain-track is that of the permissible sag. The chain is supported laterally by the sprocket teeth at the back end and by the idler-rim at the front end; over the intermediate parts it is only supported by the flanges of the supporting rollers. As the flanges of these rollers are limited for size by the closeness of the bearing surface to the ground, it will be seen that the permissible sag which may occur when crossing holes in rough ground is not very great. If supported at the ends the suspended portion of chain hanging freely will assume a curve which approximates to a catenary. For such a crude approximation as is afforded by the few suspended links of the chain-track, the curve passing through the centres of the pins is very nearly a parabola; if the curvature is small, this in turn approaches a circular arc. The worst condition for the chain occurs when there is a combination of steering and backing on rough ground; this may at the same time cause slackness in the carrying part of the chain combined with sideway thrust due to steering, and, in some of the forms of construction described, the roller flanges may be caused to ride on the chain surfaces.

One method of dealing with the difficulty is that of giving a large camber to the supporting portion of the track. In a vehicle

styled the "Centipede" built by Wm. Foster and Co., Ltd.,* the track was given a camber about equivalent to that of a 16 feet wheel. In the majority of the tractors described the curvature of the supporting portion of the chain-track is very small, corresponding to that of wheels from 90 feet to 160 feet in diameter, and in some cases even it has zero value, the part of the chain-track on which the wheels run being laid flat. This necessitates care in keeping the chain-track constantly adjusted for wear. It will be noted that this difficulty is not so serious in the chain-tracks fitted with an intermediate chain, as both the chains can sag together, and it is possible to provide deep retaining faces to keep the intermediate roller-chains in place.

The lateral pressure on the chain-track when the tractor is travelling on side-lying ground, or crossing ditches obliquely, is another factor that must be taken into account in designing the chain-track as well as the truck-frame and its connexions. Under most conditions the sideway thrust is taken partly on the flanges of the truck wheels and partly on the flanges of the driving-sprocket and idler. An arrangement which appears to provide specially for this condition is that of the Ball-Tread (Yuba), Fig. 46 (page 82). In this the whole of the lateral as well as the vertical pressure is transferred from the chain-track to the track-frame through the balls. Lateral load merely affects the angle of incidence of pressure on the ball without increase of friction. Diplock, in his recent developments of the Pedrail, has obtained the same result in a different way, by using a compound chain of rollers arranged alternately with axes horizontal and vertical, the

---

* *The Implement and Machinery Review*, 1st November, 1914, page 888. The text describes the vehicle as being "carried on twenty turned steel wheels 16 inches in diameter," but the illustration shows only four axles for carrying wheels, corresponding to sixteen wheels. Moreover the power is given as 60 b.h.p. at 1,000 revolutions per minute, the low speed as 2 miles per hour, and the drawbar pull only 4,000 lb. which correspond to an overall mechanical efficiency of about 35·5 per cent.

The radius of curvature of the track of the experimental tractors made in England about 1904 was also about 16 feet.

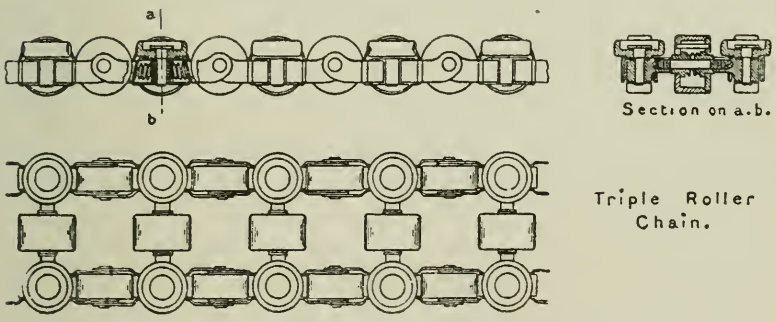
track-frame and bearing surfaces of the chain-track being made with appropriate faces for receiving the vertical and lateral loads respectively, Fig. 54.

TRACK SHOES.

For travelling on rough country and under general agricultural conditions the pressed steel shoe is found satisfactory, Fig. 56, Plate 8. In this case the supporting surface for the rollers consists of a steel casting, or case-hardened drop-forging, bolted to the shoe; in other cases the track shoe and supporting surface are formed in

FIG. 54.

Roller-chain for Pedrail (Diplock).



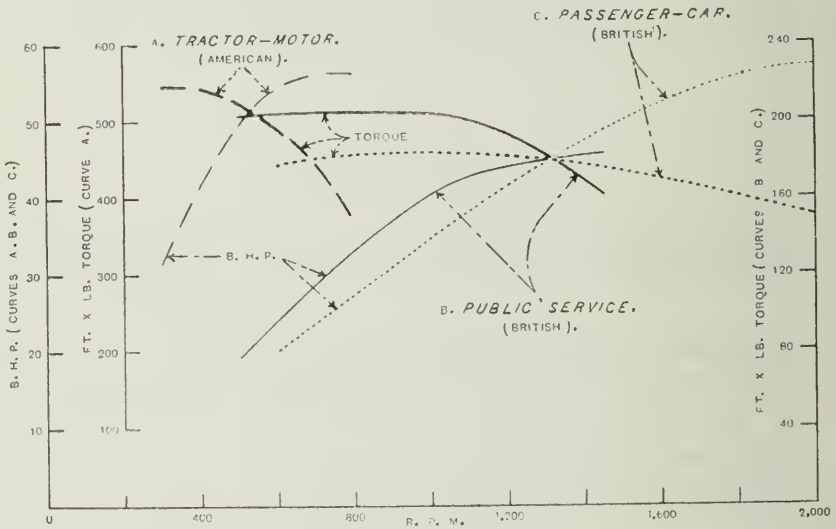
one as a single steel-casting, Fig. 57, Plate 8. Where the ground surface presents small resistance to shear, or actually lubricates the shoes, as is the case with clay and chalk and some grass surfaces, it is sometimes found necessary to attach grousers or spuds of angle-bar to the shoes by means of bolts. When the tractor is required to do hauling on ordinary roads it may be necessary to attach thin sleepers of hard wood to the shoes in order to provide a flat bearing and prevent damage to the road surface. Those chain-tracks which present fairly flat surfaces to the road and are not excessively cambered—the lower-powered

Caterpillars, Clayton, and Burford-Cleveland for example—can be run over inferior roads with even less risk of damage than would occur with the ordinary driving slats of the common traction engine.

Engines.

The internal-combustion engines fitted to chain-track tractors are generally of a type resembling that used for heavy lorry or

Fig. 58.—*Torque and Horse-Power Curves for Motors.*



truck work. There is no reason for great economy in weight, and indeed the weight of the vehicle must not be too small for the tractive effort; consequently cast-iron is preferred to aluminium for the engine and also for the gear-box. A governor is usually fitted to prevent racing the engine. That care which is taken in designing the passenger-car engine to obtain a flat torque curve, and which is accompanied by large diameters of valves, induction and exhaust passages, is not called for here. The torque curve consequently falls rapidly at a comparatively low speed. This, as is generally recognized by the makers of engines for commercial

vehicles, is not without advantage, for when the resistance to traction becomes unduly heavy, owing to gradient or softness of the ground, and the speed of the engine is consequently reduced, the torque increases and the driver has a better chance of extricating the vehicle from its difficulty without changing gear than is the case with constant torque. A typical torque curve of one of these engines is given in Fig. 58. The tractor engine runs at a low piston speed, 600 to 900 feet per minute; that is, at barely one-half the speed usual for the passenger-car engine. On the other hand, it is required to work at a greater percentage of its full power than is the case with the passenger-car engine, and for considerations of fuel economy it should, in general, be designed to give its best efficiency, measured in b.h.p. per gallon per hour, at from 50 to 70 per cent. of its full rated capacity. In many instances the engines are designed to start on petrol (gasolene) and to run normally on paraffin, or, in America, on "distillate"; * this also implies a larger engine for the power than is the case where petrol or benzole is the usual fuel.

Lubrication of the engine is usually ensured by the splash system, but in some instances a combined splash and forced lubrication system is fitted. Separate oil reservoirs are of course required for the engine-lubricating oil and for the crude black oil used for the track-chains.

Ignition and Starting.

The usual form of ignition is the high-tension magneto. Self-starters are not fitted, as they would involve too much additional complication. Owing to the large size of some of these engines, and the difficulty of starting by swinging the starting crank-handle, a trip-gear is arranged on the magneto which enables a strong sparking current to be obtained for a small movement of the cranking handle. This arrangement was used by the Author in 1895 on gas-traction tramcars, the engines of which were started by pulling over the fly-wheel. The combined use of petrol for starting

* "Distillate" is a low-grade spirit about 0·770 to 0·780 density.

and paraffin for running complicates the carburettor and piping arrangements slightly, and involves fitting an extra tank, but the advantage of ease in starting is well worth this.

Radiators.

The radiators of chain-track tractors have been designed to meet the exigencies of the working conditions. The cooling surface must be large to enable the engine to run continuously under heavy load in the heat of summer; and a fan, if fitted, must be easy of access and simple in its driving gear. The water-supply carried must be sufficiently large to last for a long journey of perhaps a whole day away from the base station; for this reason a large tank for water, or equivalent radiator capacity, is provided in most models. Finally, it is necessary that the whole water system should be capable of being drained at its lowest points, to avoid risk of damage by frost when the machine is laid up in winter.

As the machines have to work in places distant from large manufacturing centres, it is moreover advisable that the design of radiator should admit of its easy removal from the vehicle, of ready access to its water joints, and of the possibility of executing repairs without special tools and appliances. The conditions of the problem are similar to those of the motor omnibus; more severe regarding the total cooling to be effected, and less severe in weight restrictions. The type generally adopted is the vertical gilled-tube with top and bottom reservoirs; in some of the lower-power tractors these reservoirs are made of sufficient size to avoid fitting a separate water tank. The water circulation is usually forced by means of a centrifugal pump or by a gear pump, the former type being the more common.

Speed of Tractors.

At normal revolutions per minute of the engine the lowest or first speed of the majority of chain-track tractors varies from 1·25 to 2·25 miles per hour; on the second speed from 2 to 3·5 miles per hour, and on the third or top speed, where such is fitted, from 3 to 5·5 miles per hour,

The changing of gear is usually effected by sliding gears or dog-clutches in a gear-box of motor-lorry type, the main clutch being disengaged for gear-changing or reversing. Cut steel gears, case-hardened, are usual for spurs and bevels; plain bearings are commonly fitted in the gear-boxes, which are of heavy design and usually of cast-iron; ball-bearings are only used in a few instances. In the Caterpillar and Creeping-Grip tractors transmission to the back axles is by chain-drive; in the Tracklayer and Ball-Tread it is by spur-pinions gearing into an internal gear-wheel formed in one with the driving sprocket.

It is curious that in these heavy slow-moving vehicles the epicyclic form of gear-change, usual on American passenger cars, should have found no practical application. This is the more remarkable as the difficulty of gear-changing with sliding gears or dog-clutches is greater with governed engines.

Drawbar Pull.

Chain-track tractor makers are nearly unanimous in their estimates of the loss of power that takes place between the engine and the ground. The power delivered at the track is estimated at from 70 per cent in the large 100 h.p. tractors down to 55 per cent in the small tractors of 30 h.p. and under. The force required to haul the track itself apparently varies from 15 per cent of the weight carried in the fixed roller type with plain bearings, to 2 per cent of the weight carried in the travelling roller type of track, or its equivalent.

The difference between the two constructions in loss of tractive effort may be attributed in part to the fact that it is easier to ensure efficient lubrication in a roller system that is loaded intermittently, than in one which is subjected to continuous load in one direction.

The comparatively heavy resistance to traction in those chain-track tractors in which the load is carried through rollers running on fixed axles is reduced in some cases by fitting roller bearings, of the Hyatt pattern for instance, on the roller-wheel shafts. These do not, however, reduce the lateral friction on the flanges and bosses of these wheels, which depends on the supply of grease that

can be forced in through the pins by lubricators of the Stauffer type. Roller bearings so fitted will, of course, reduce the starting effort; nevertheless, it appears to the Author that, of the several sources of friction contributing to losses in the chain-tracks, the lateral friction of parts of the system of carrying rollers, where the rollers revolve on fixed axes, probably accounts for more than half the total loss of tractive effort.

Experience, gained in comparative tests of the fixed-axles and roller-chain systems made over a long period under the same working conditions, will be necessary to determine the cost of upkeep of each; the same tests will also show how far the extra complication of the intermediate travelling chain of rollers is compensated by reduction in fuel consumption.

CLIMBING POWER.

The drawbar pull varies in different types of vehicle from 30 per cent to over 70 per cent of the weight of the vehicle; a heavy tractor weighing 28,000 lb. can exert a drawbar pull of 12,000 lb.; a small tractor of 30 h.p. can exert a pull of 3,500 lb. The steepness of gradient that these vehicles can climb is consequently very great.

On railways gradients are measured as the tangent of the angle of inclination, the rise being referred to the plan of the track. In the case of hill-climbing tests of automobiles the maximum gradient climbed rarely exceeded 1 in 3; for this value of the tangent, the angle with the horizontal is 18° 26′, of which the sine is 0·3162; that is to say, the actual length of the road, in elevation, is about 5 per cent more than that given in plan. As some chain-track tractors are capable of climbing a gradient as steep as 45°, it is necessary to refer climbing and haulage problems to the actual road length, which for an inclination of 45° is over 40 per cent greater than the length in plan. Thus a vehicle capable of exerting a draw-bar pull equal to 50 per cent of its weight can climb a slope of 30° provided that the ground presents sufficient adhesion; and a vehicle capable of exerting a drawbar pull equal to 71 per cent of its weight can climb a slope of 45° provided that a sufficient bite can be obtained by the tracks on the surface.

The tractive effort for ordinary railway practice at speeds not exceeding 5 miles per hour, and therefore free from questions of air resistance, varies between 9 lb. per ton (0·4 per cent) for the train hauled, and 12·5 lb. per ton (0·55 per cent) for the train including engine and tender; on tramway rails the tractive effort varies from 30 lb. per ton (1·34 per cent) wet, to 56 lb. per ton (2·5 per cent) dry; or ordinary roads the effort varies from 70 lb. per ton (3·1 per cent) on macadam to 120 lb. per ton (5·4 per cent) on good gravel roads, and it is much more on bad gravel roads and across fields. The inclination of the ground on which chain-track tractors will roll back varies from 1 in 7 for the fixed-axle plain-bearing roller type, to 1 in 50 for the independent roller-chain or its equivalent.

In comparing chain-track tractors with other vehicles for resistance to traction it must, however, be remembered that the resistance with fixed axle-wheels, which may amount to 14 per cent for the tractor itself with its gear, or to 9 per cent for a trailing tractor, is not greatly increased by conditions under which a wheeled vehicle sinks so deeply that the tractive effort required to haul it may amount to 40 per cent of its weight. Conditions produced by swamp or sand can be such that no horse or wheeled tractor could haul the load at all, yet they will present no difficulty to the chain-track tractor.

Drawbar Connexion.

In vehicles exerting so heavy a drawbar pull as is possible with the chain-track tractors, it is of great importance that the drawbar connexion should be placed as low as practicable without unduly reducing the ground clearance. The couple formed by the drawbar pull at the height of the drawbar, and the ground resistance, acts on the frame of the tractor in the same direction as the couple due to the tractive effort applied at the sprocket teeth; both tend to cause the front of the tractor to rise, and, as will be seen from Table 2 (pages 146 to 151), the portion of the load carried on the front wheel is usually small. For this reason it is advisable in designing vehicles of short base and heavy drawbar pull that the drawbar

shall be placed low. In vehicles intended for soft and marshy ground it is desirable to use wider treads rather than to attempt to obtain very great ground clearance for the drawbar. For this reason many makes are fitted with alternative widths of chain-track according to the land on which they are to work.

Leading Features of Tractors.

The horse-power, engine dimensions and speed, tractor speeds forward and reverse, track width, length of the track in contact with the ground, weight on track, weight on steering wheels (if any), load per square inch of track, dimensions of steering wheels, radius of turning circle, pitch of chain, capacity of petrol, water and oil tanks, drawbar pull, and ratio of drawbar pull to weight of tractor are given in Table 2 (pages 146 to 151).

Some further particulars of the characteristic features of the several types may now be given.

The Log-Hauler, Phœnix.

The Log-Hauler (Phœnix) was first used in 1904, and engines of this class were supplied to Montana in 1906; many are in use in Wisconsin. One of these vehicles is shown in Fig. 59, Plate 9. In early logging a team of four bullocks hauled a sleigh carrying about 1,500 feet of timber, or a weight of about 8 tons. The present day sleigh is from 7 to 8 feet wide from centre to centre of runners, with cross bunks, 12 to 16 feet apart, on which loads are built up, Fig. 62, Plate 10; the load for an individual sleigh amounts to from 5,000 to 7,000 feet, and the train consists of from seven to fifteen sleighs, or a weight of 200 to 420 tons, Fig. 64, Plate 10.

The Log-Hauler has a locomotive-type multitubular boiler with barrel 15 feet long, 36 inches diameter, with 1·75-inch tubes, the working pressure being 200 lb. per square inch. Coal or wood fuel is used. The engines are vertical with two double-acting cylinders, 6·25-inch bore, 8-inch stroke, with link-motion reversing gear on each side, Fig. 60, Plate 9. Each drives through spur-gearing into a lay-shaft which itself drives at the back through a bevel-

pinion into a bevel-wheel fixed to a spur wheel which is free to revolve on the back axle. This spur wheel gears through an intermediate spur wheel into the rear sprocket, Fig. 60, Plate 9; the front sprocket is an idler. The back sprocket gears into the outer or lag-chain of shoes, which is the track-chain; the centres of the pins are about 2 inches from the face of the shoe, which is fitted with a $\bigwedge$ projection to grip the frozen surface on which the Log-Hauler travels. There is no special provision in this case for guarding the joints of the chain-track. A screw adjustment is provided for taking up stretch of the lag-chain by acting on the front sprocket bearings. There are two intermediate roller chains with case-hardened rollers 3 inches diameter and about 2 inches wide for each track; these roller chains run on tool-steel guides secured to the underside of the truck frame, and are guided at the sides where they pass over the carrying segments. Lateral pressure is taken on the sprockets. The speed of running is from 4 to 5 miles per hour. The load hauled depends not only on the grading of the road but on how well it has been iced. The crew consists of the engineer (driver), a fireman, and the pilot; the latter sits in front of the smoke-box, so that he can see both the road and the runners, Fig. 63, Plate 10. The steering column is inclined backwards, and drives through a worm into a cross shaft which is connected by chains to the ends of the cross beam of the runners. The coal consumption is stated to be from 56 to 84 lb. per mile. The engines require special housing arrangements, similar to those provided for locomotives in Canada or Russia, as they have to work in country where the night temperature may fall as low as $-50°$ F. The tractors have to haul their own water supply, and may also be required to plough the track clear of snow. Provision is made for attaching a plough clear of the runners.

The illustrations, Figs. 62–65, Plates 10 and 11, show the methods of building up the loads and trains of sledges both for log and sawn timber; they also show the small ground clearance allowed in this particular type of tractor, and the curve that can be taken by the train.

The Centiped Truck, Phœnix.

The Centiped, Fig. 66, Plate 11, resembles the Log-Hauler in the pivotal arrangement of the track frames, and in the construction of the lag-chains and roller-chains. Both axles are carried on springs. The steering is of the Ackermann type with the front axle pivoted about a horizontal axis, so that the vehicle has virtually a 3-point suspension, and either front wheel can be taken over an obstacle 10 inches high. This is a very necessary feature in tractors fitted with two front wheels, as they are frequently required to cross ditches obliquely, Fig. 68, Plate 12, or banks of railway tracks, Fig. 69, Plate 12. Examples of the Centiped at work are given in Figs. 71 and 72, Plate 13. Power is transmitted through a three-speed and reverse gear-box to the differential shaft, and thence to the rear sprockets in a manner similar to that adopted in the Log-Hauler.

The track adjustments, Fig. 70, Plate 12, are of the same type as on the Log-Hauler, but the construction of the chain-track is different. The centres of the pins are arranged unusually far from the face of the shoes, this dimension being about 5 inches; but to avoid nut-cracker action each shoe overlaps the one in front by about 2·5 inches on the flat and 1 inch at maximum curvature. Each shoe carries a strake about 2 inches wide by 1 inch thick. The small amount of sinking of the track on soft sand, as compared with that of the wheels, is shown in Fig. 67, Plate 11.

The Allis-Chalmers Tractor-Truck.

This vehicle, Fig. 73, closely resembles the Centiped in general arrangement of gears as well as in the design of the chain-tracks and of the roller chains. It is fitted with an engine of higher speed, of 68 b.h.p., and is peculiar in having four forward speeds, the third speed on direct drive giving about 6·2 miles per hour, and the indirect-driven fourth as high as 7·5 miles per hour. The springing of the front axle is effected by two heavy coil springs; the back axle is carried on two side springs of the semi-elliptic sliding type, each 54 inches long by 3 inches wide, and supplemented by a cross-spring, 30 inches long by 3 inches wide. The front-

wheels run on roller bearings. A special feature of the design is the large road clearance permitting the vehicle to be used over very rough ground or in deep snow. The Allis-Chalmers Tractor weighs about half a ton more than the Centiped, but has approximately the same insistent weight.

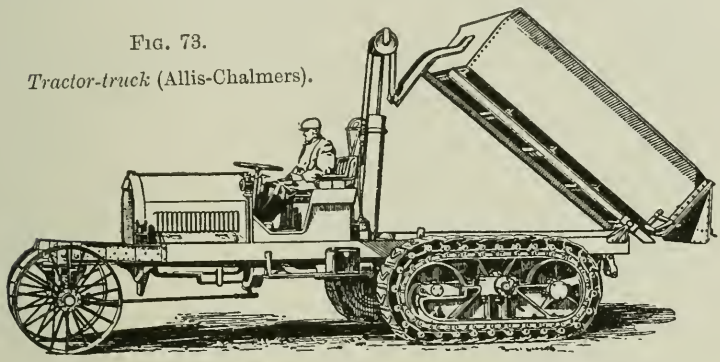


FIG. 73.
Tractor-truck (Allis-Chalmers).

THE CATERPILLAR, HOLT.

The load is carried in the Caterpillar (Holt) from the central portion of the chain on five pairs of chilled cast-iron flanged wheels. The wheels run on heat-treated steel axles fitted with Hyatt roller bearings. The pairs of wheel flanges are alternately inside and outside the bearing surfaces of the track-chain. The track-links are either of annealed steel castings, as in the 120 h.p. model, Fig. 57, Plate 8; or are built up of steel drop-forgings machined on the upper face, Fig. 56, Plate 8, and secured to pressed steel sole plates; the shoes have each two corrugations about 1·5 inch wide for gripping the ground; the pins are of case-hardened steel. The bearing faces are 2·5 inches wide in the 75 h.p. and 2.25 inches in the 45 h.p. model. As there are two lines of rail surfaces on each chain, the total effective rail-width is 10 inches for the 75 h.p. and 9 inches for the 45 h.p. models respectively. The truck in both the 120 h.p. model, Fig. 74, Plate 13, and in the 75 h.p. model, Fig. 75, Plate 14, and Figs. 86–88, is in a single piece, and

FIG. 86.

Caterpillar; 75 h.p., Side Elevation.

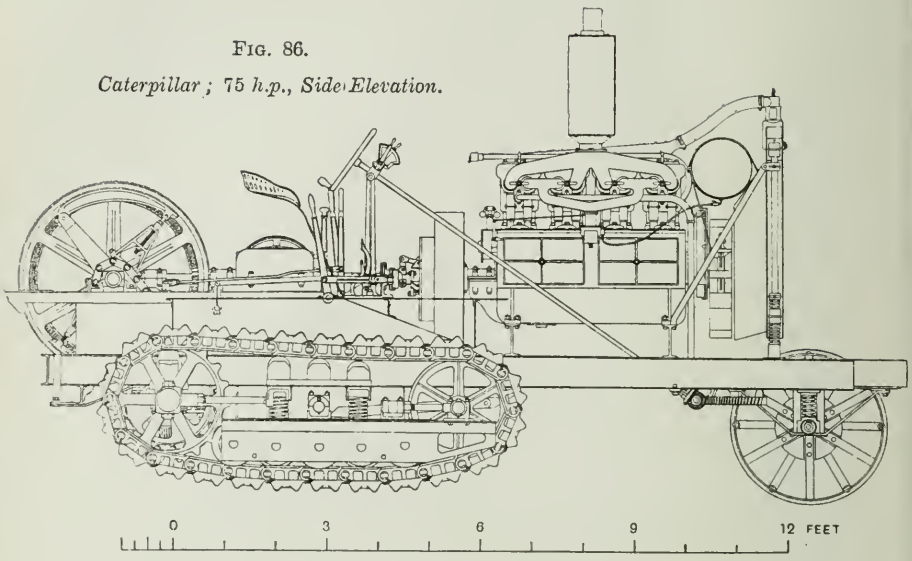
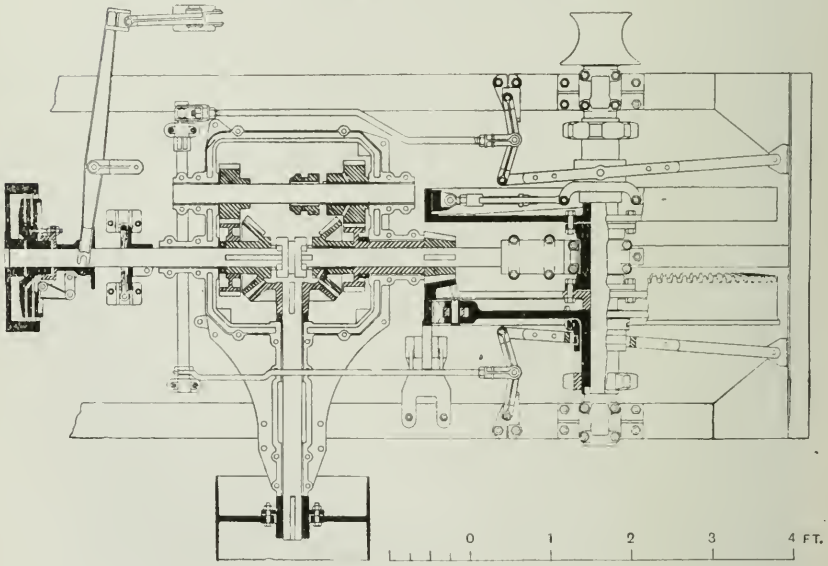
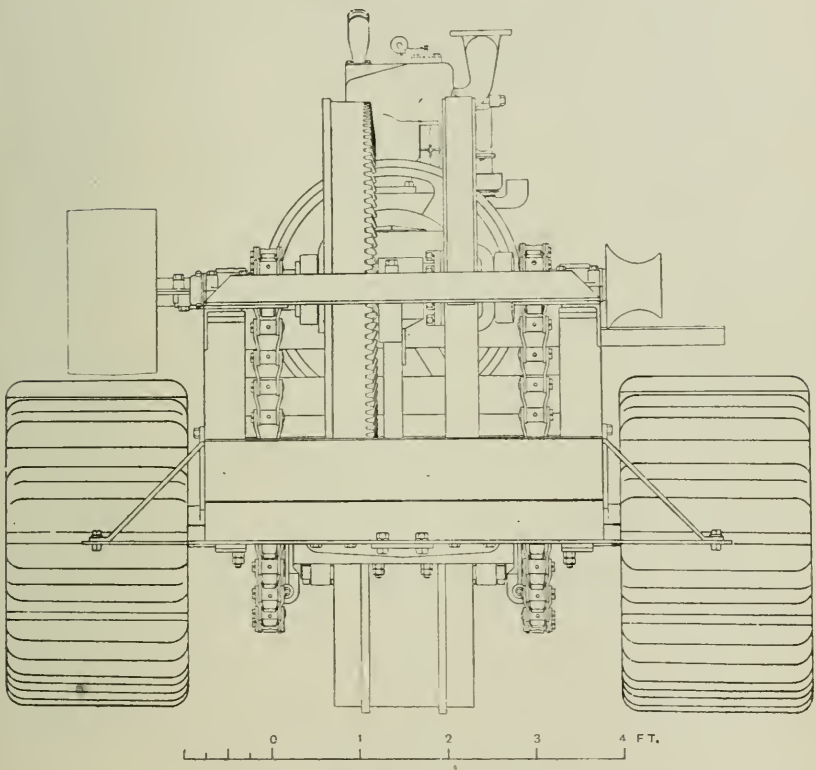


FIG. 87.—*Caterpillar; 75 h.p., Transmission, Plan.*



is connected to the axles by two links, of which the front one is fitted with a screw adjustment but is allowed freedom for vertical movement relatively to the track-frame; the load is carried by four double-coil helical springs on each side. The unsupported portion of the chain-track between the sprocket or idler and the adjacent

FIG. 88.—*Caterpillar; 75 h.p., End View.*



wheel at each end is about $1\frac{1}{2}$ links in length. The steering is effected by a single front wheel controlled by a non-reversible worm and wheel gear.

Power is transmitted from the engine through a multiple-disk clutch with five plates, bronze to cast iron, to a simple reversing

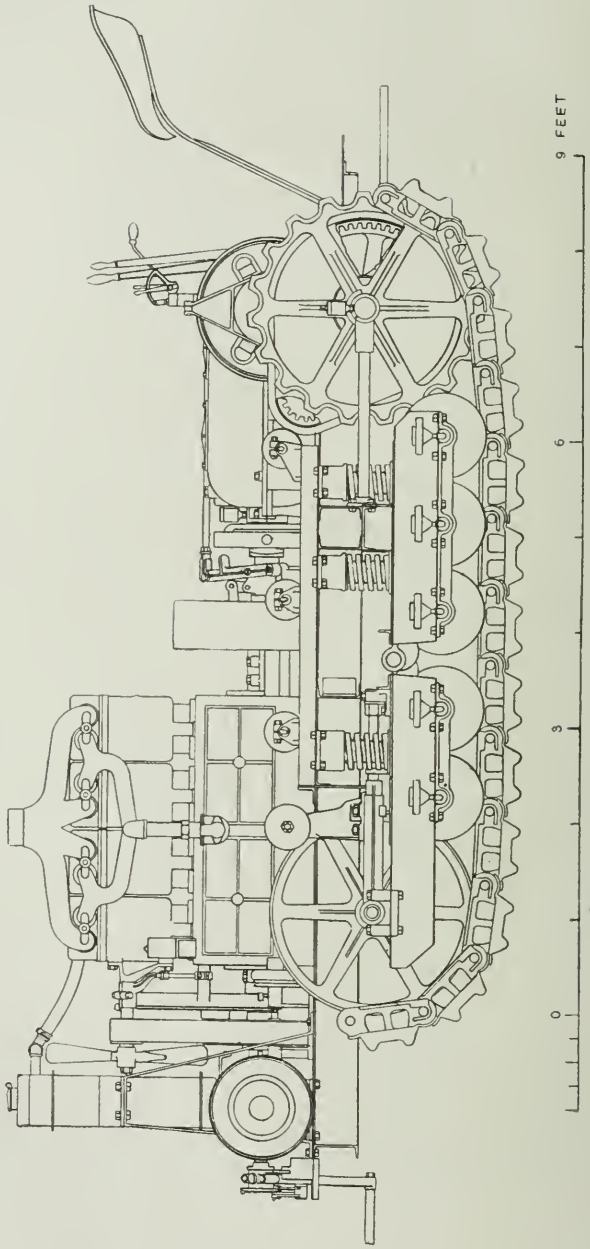


FIG. 89.

Caterpillar; 45 *h.p.*, *Side Elevation.*

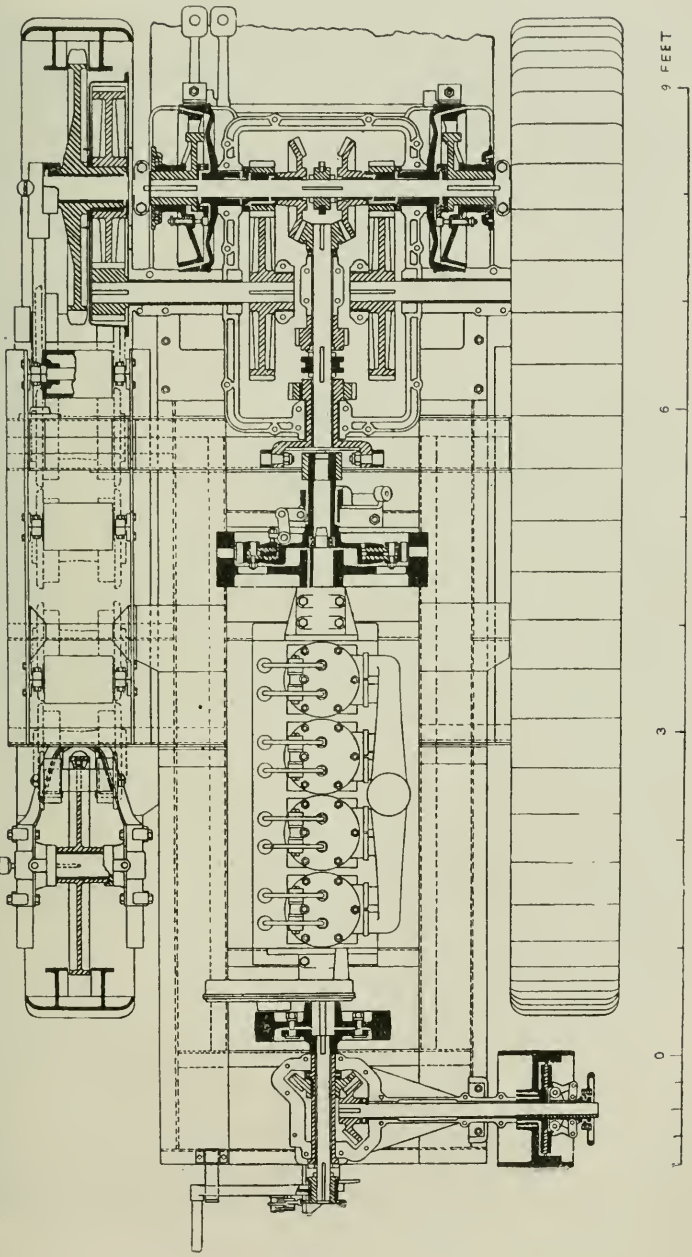
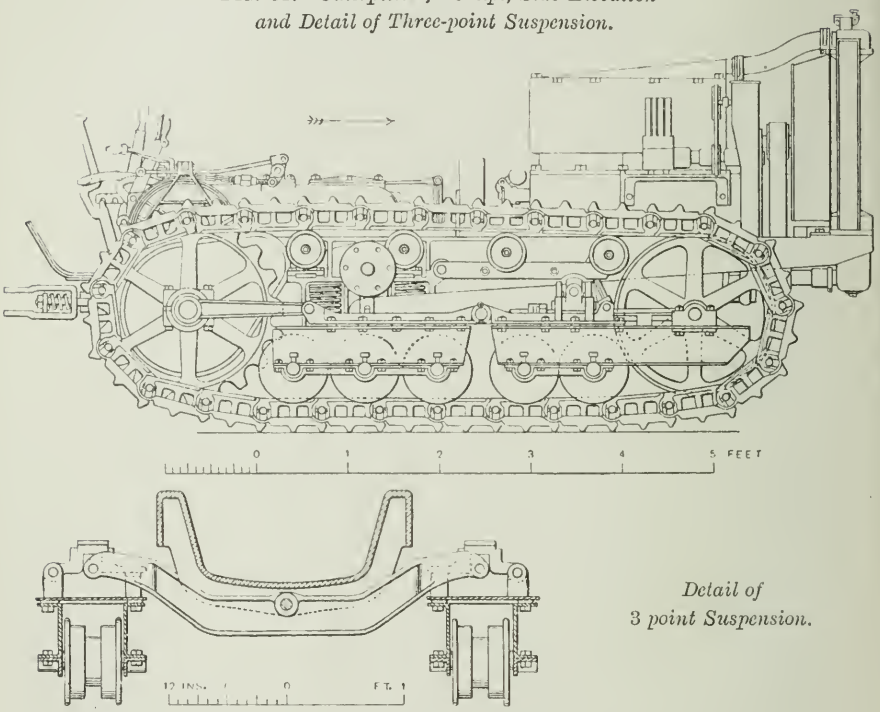


FIG. 90.—*Caterpillar*; 45 *h.p.*, *Transmission*, *Plan*.

gear-box with two speeds and reverse; the drive-shaft is spring-driven to reduce shock in taking up the load; the track sprockets are driven by chains; there is no differential gear, but friction clutches are fitted on both sides so that the drive may be on either side to facilitate turning. Examples of Caterpillars at work are given in Figs. 81–85, Plates 16 and 17.

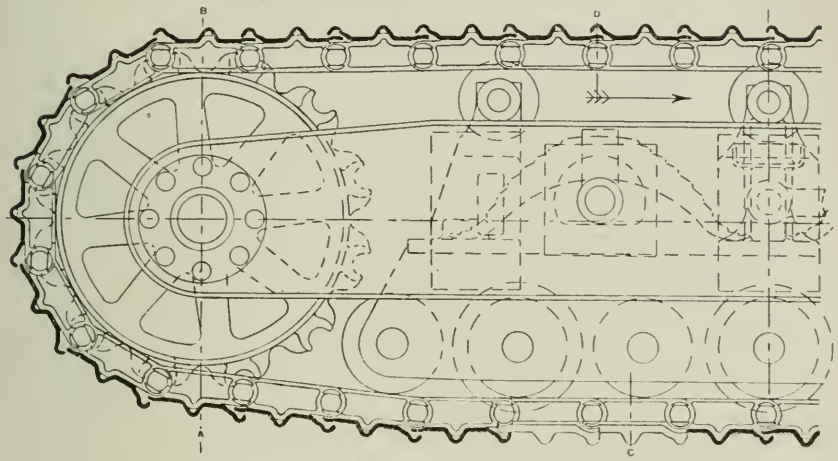
FIG. 91.—*Caterpillar;* 18 *h.p., Side Elevation and Detail of Three-point Suspension.*



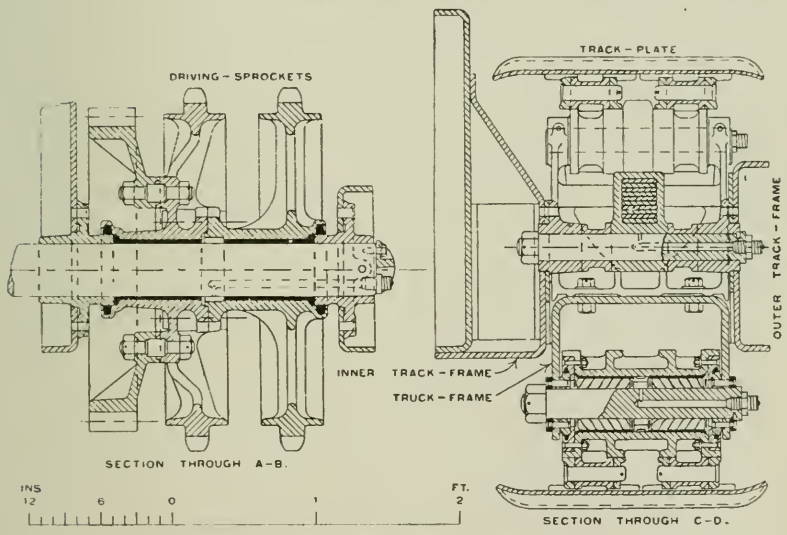
Detail of 3 point Suspension.

In the smaller models, 45 h.p., Fig. 76, Plate 14, and Figs. 89–90, and 18 h.p., Fig. 78, Plate 15, and Fig. 91, there is no front wheel, and the steering is effected entirely by separate clutches and brakes; the turning radius is controlled by pressure on a foot pedal. The truck-frame is itself articulated in these models, Fig. 51 (page 87), the leading half of the truck having two wheel axles and

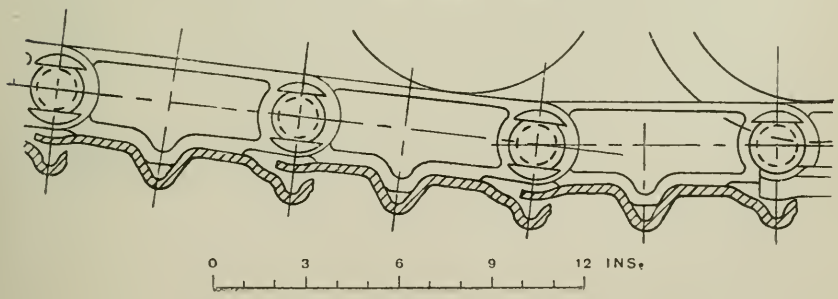
FIG. 95.—*Clayton* 110 *h.p. Tractor, Track-Frame and Details.*



Chain-Track Section. . . . . Elevation. . . . . Section.



Detail of Chain-Track and Wheels; Enlarged View.



the back half three wheel axles, in both the 45 h.p. and 18 h.p. models; the springing of the back half of the truck from the main frame is very similar to that adopted in the larger models, but the front halves of the truck are connected by pin-joints to a transverse compensating beam pivoted horizontally and axially with the vehicle, Fig. 91, so that actually there is 3-point suspension and freedom for the truck-frames to accommodate themselves to irregularity of the ground.

The Clayton Tractor.

This tractor, Fig. 92, Plate 18, was produced by Messrs. Clayton & Shuttleworth jointly with Mr. W. F. Rainforth, Director of the Munitions Mechanical Transport Department. It is the sole representative of high-power chain-track vehicles of British design and manufacture, has fixed centres for the sprocket and idler as in the Caterpillar (Holt), but the arrangement of the truck is different, a single link connecting the truck to an anchor pin fixed to the track-frame, Fig. 48 (page 84). The load is carried on each truck by two inverted laminated springs about 2 feet long, each consisting of ten plates 3 inches by 0·3 inch, Fig. 95. There are seven supporting wheels, alternate wheels being flanged; those next the driving sprocket and the idler are without flanges. The length of chain unsupported between the end wheels and the sprocket or idler is nearly two chain-links in length. The links are built up of steel castings and pressed-steel shoes, Fig. 95; the latter have a central corrugation about 2 inches wide by 1·5 inch deep. Another corrugation is formed in the end of the sole plate that laps over the succeeding plate. The pin centres are kept very low, being only 2 inches from the under surface of the sole. An adjustment is provided for the bearings of the idler axle to take up wear.

The steering gear of this tractor is quite original in pattern, and consists of a single front wheel carried at the end of a projecting boom, Figs. 96 and 97. This is capable of being raised or depressed through a range of 15° each way from normal, so that its position in relation to the track can be adapted to severe irregularities in the ground; it is not, however, necessary to use the elevating gear

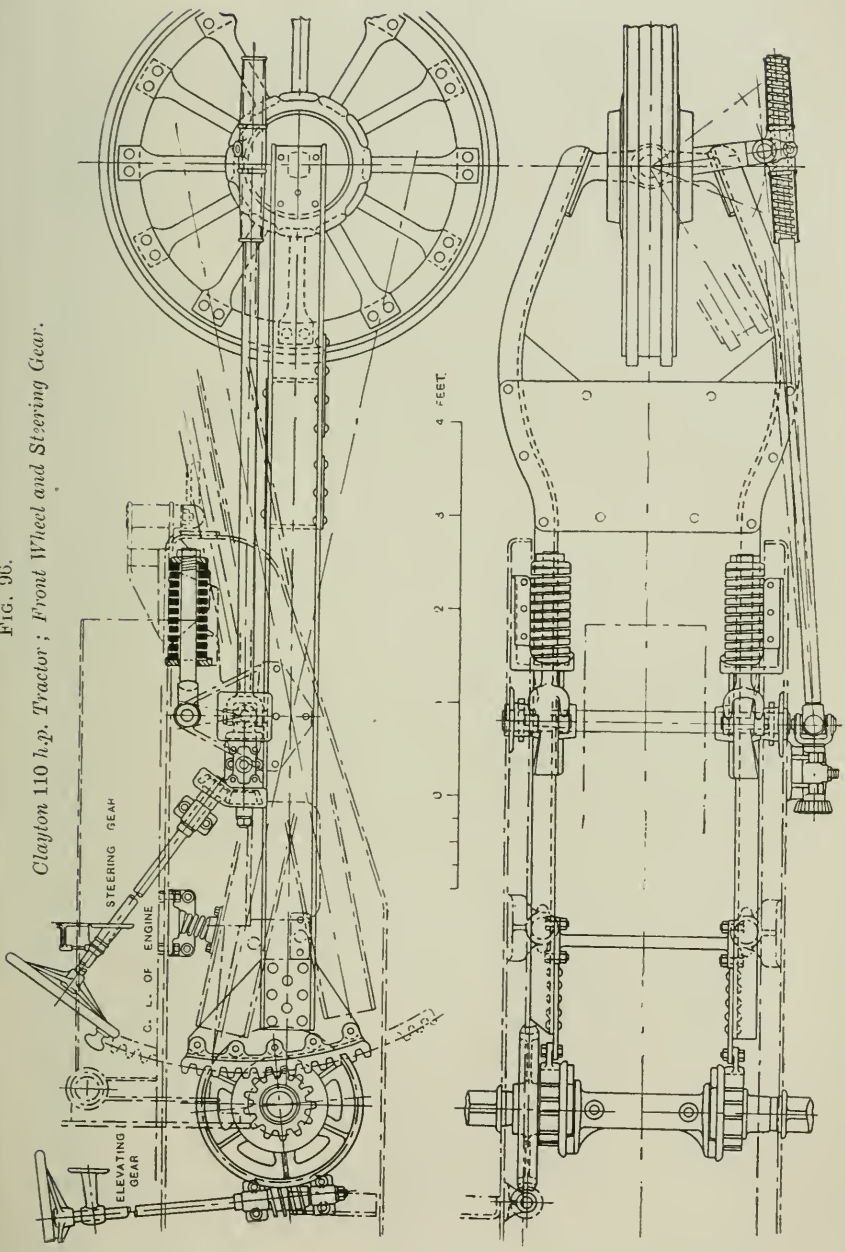


FIG. 96.

Clayton 110 h.p. Tractor; Front Wheel and Steering Gear.

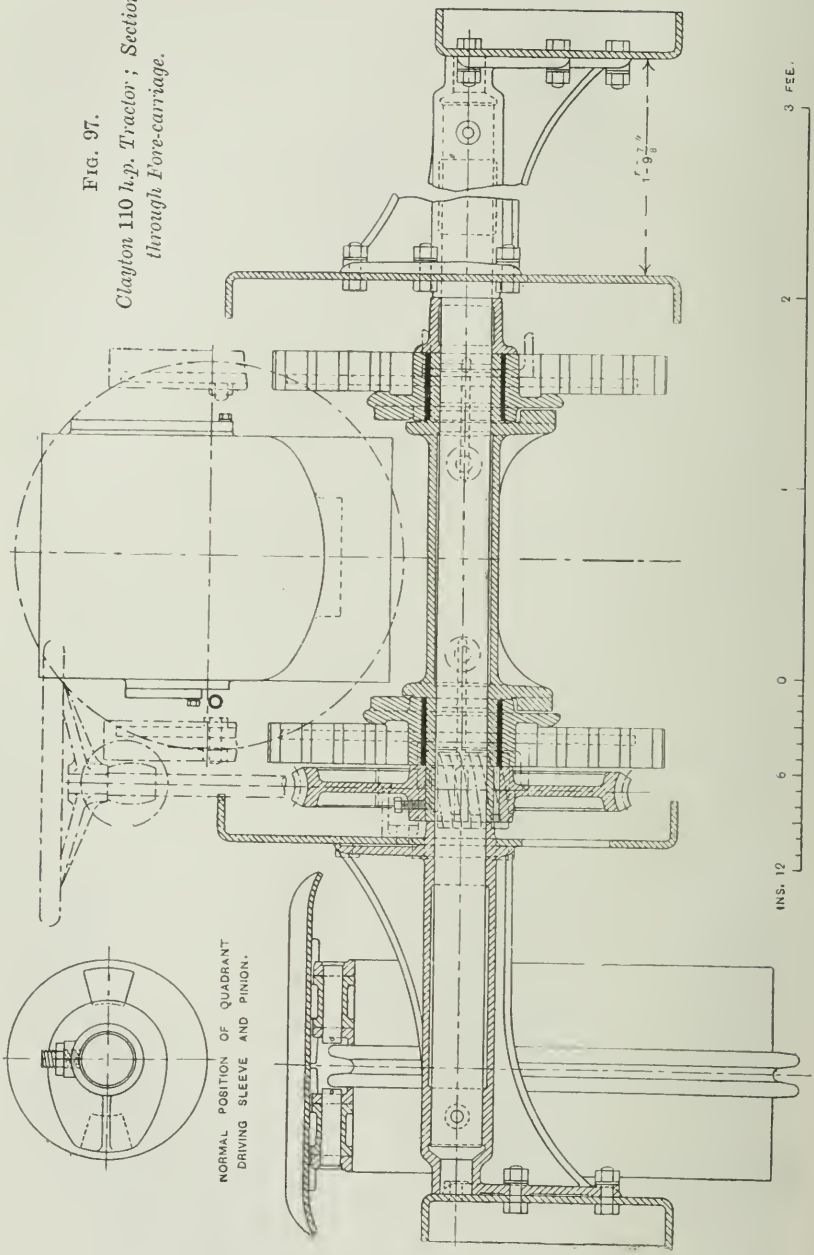


FIG. 97.
Clayton 110 h.p. Tractor; Section through Fore-carriage.

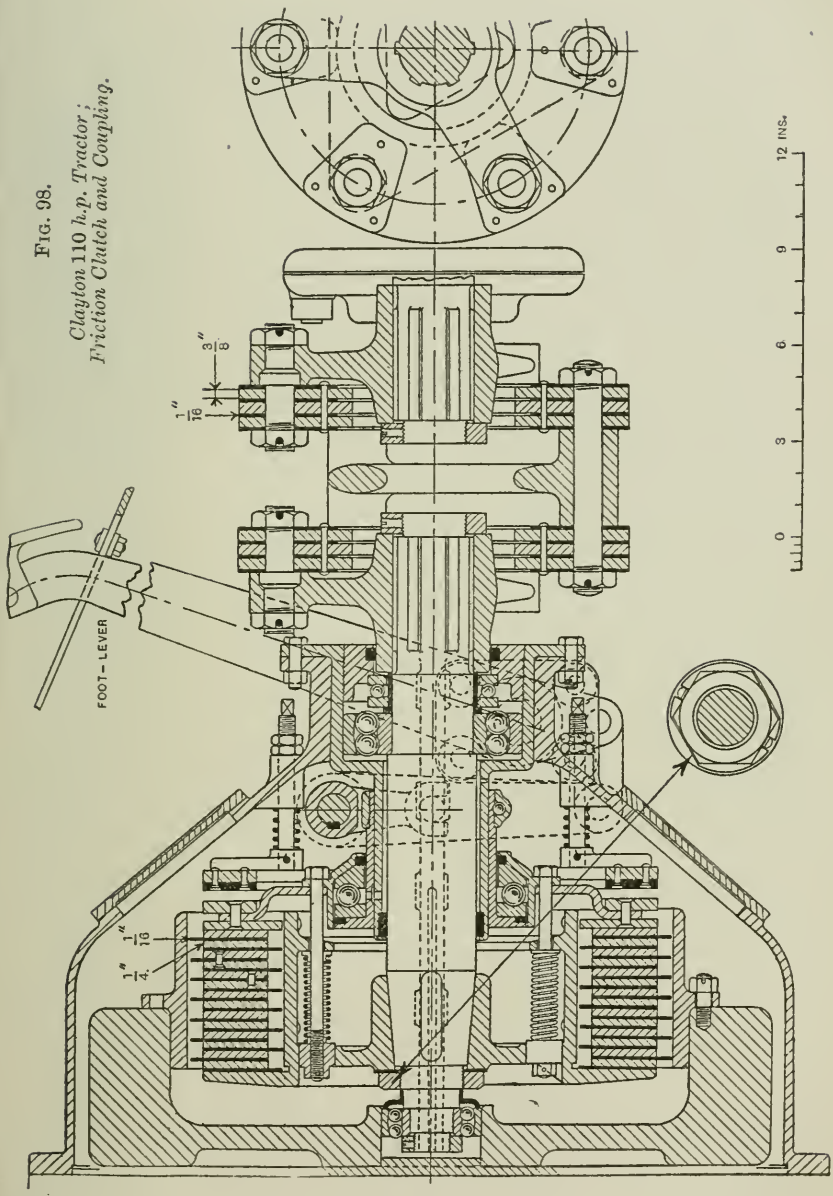


FIG. 98.

Clayton 110 h.p. Tractor; Friction Clutch and Coupling.

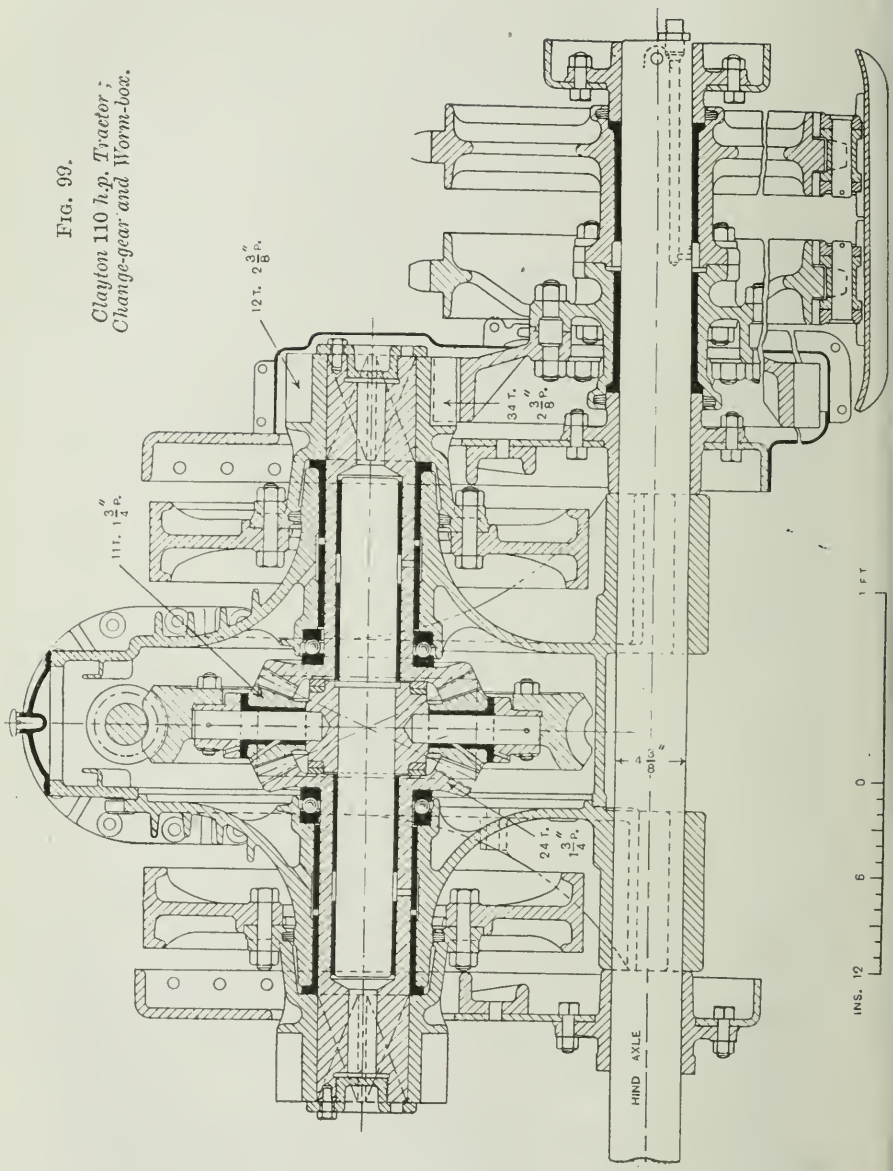


FIG. 99.

Clayton 110 h.p. Tractor ; Change-gear and Worm-box.

otherwise than for approximate adjustment, as a spring gear is fitted which provides for the range of movement in each direction.

Power is derived from a 110 h.p. petrol engine, constructed by the National Gas Engine Co., Ltd.,* and is transmitted through a multiple-disk clutch with seven steel plates bearing on ferodo surfaces; the clutch shaft runs on ball-bearings. A flexible coupling with tripods connected by triple leather disks provides for possible errors of alinement between engine and gear-box, Fig. 98. The gear-box has three forward speeds and a reverse, change of gear being effected by means of the usual motor tractor sliding gear to a worm shaft, Fig. 99; the latter drives into a bronze worm-wheel, inside which the differential-gear pinions are carried. The differential bevels are each formed in one with a short hollow shaft, the interior of which is bushed to receive a short independent shaft, on which the worm-wheel centre is free to revolve. The ends of the bevel-wheel shafts are squared, and each fits into a driving pinion, which carries a brake drum on its inner side and engages with the gear-wheel attached to the twin sprockets. The sprockets are spigoted and bolted together, and to the spur wheel, and the whole arrangement is bushed and runs on the fixed back axle. All shafts are fitted with lubricating devices for enabling grease to be forced between the bearing surfaces. In each chain there are four bearing surfaces for the wheels, each 1·5 inch wide, giving an aggregate carrying width of 12 inches for the two tracks.

Steering is assisted by applying brakes independently to the pinion brake drums.

The Clayton tractor is shown in Fig. 93, Plate 18, hauling a test load, and in Fig. 94, Plate 19, climbing a 40° gradient; the illustration shows how the front wheel leaves the ground at the top of the grade. The shock that would occur when the bank is climbed, and the machine again assumes the level, is in greater part or entirely absorbed by the springs controlling the projecting boom, Figs. 96 and 97.

* This motor was constructed to the designs of the Ministry of Munitions Mechanical Transport Department, the Director of which was Mr. W. F. Rainforth. A very full description of the engine is given in *The Engineer*, vol. 123, pages 308, 310–11, 314 and Supplement.

The 35 h.p. Clayton tractor, Fig. 100, resembles the smaller American models in the absence of a front wheel; steering is effected by clutches and brakes operated through a steering wheel.

The change-gear provides two speeds forward and one reverse, and drives through clutches into two lantern pinion carriers on the driving-shafts, each gearing with its respective driving sprocket; the sprocket engages with the chain-track pins in every third tooth.

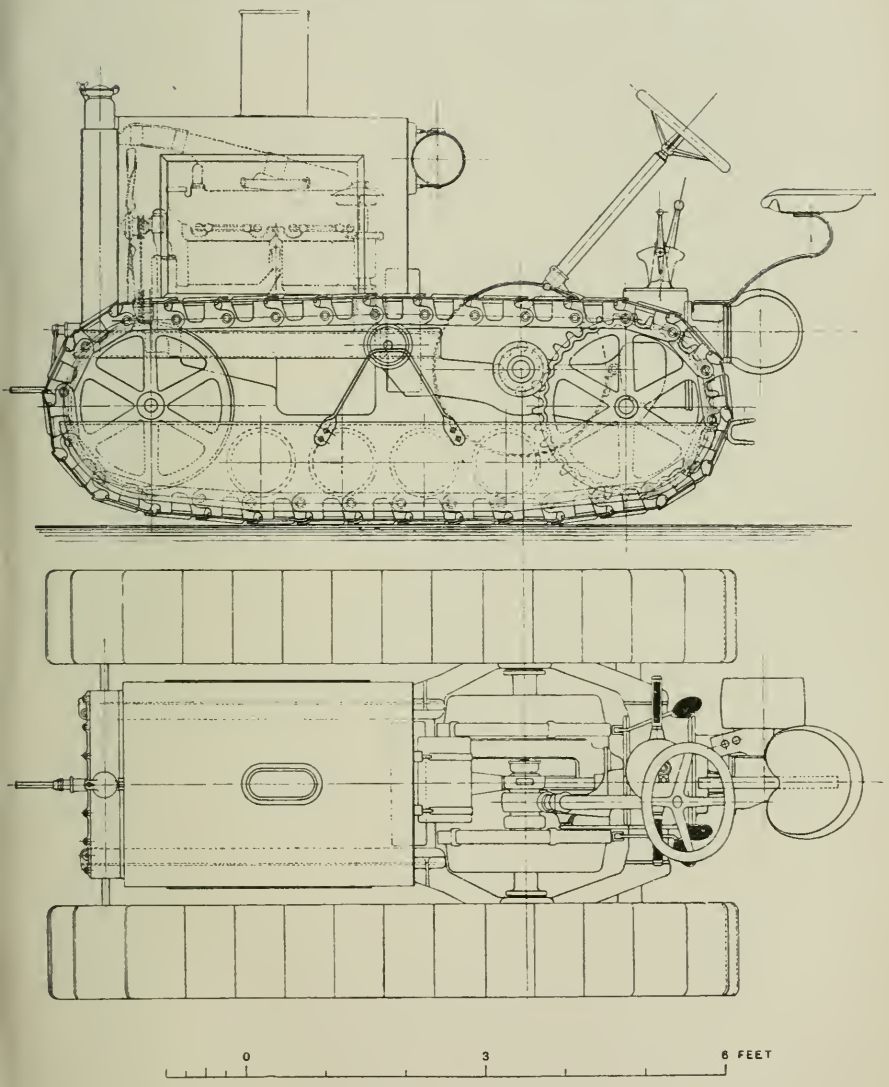
Each chain-track supports the vehicle through four fixed-axle wheels, the slack of the chain being carried on a single wheel; each chain passes over an idler at the front of the vehicle.

The tracks are pivoted about the driving shafts, the load at the front end being carried on a front axle which allows the two tracks to move independently of each other, and by means of a special connexion, to move only in a vertical path.

The Tracklayer, C. L. Best.

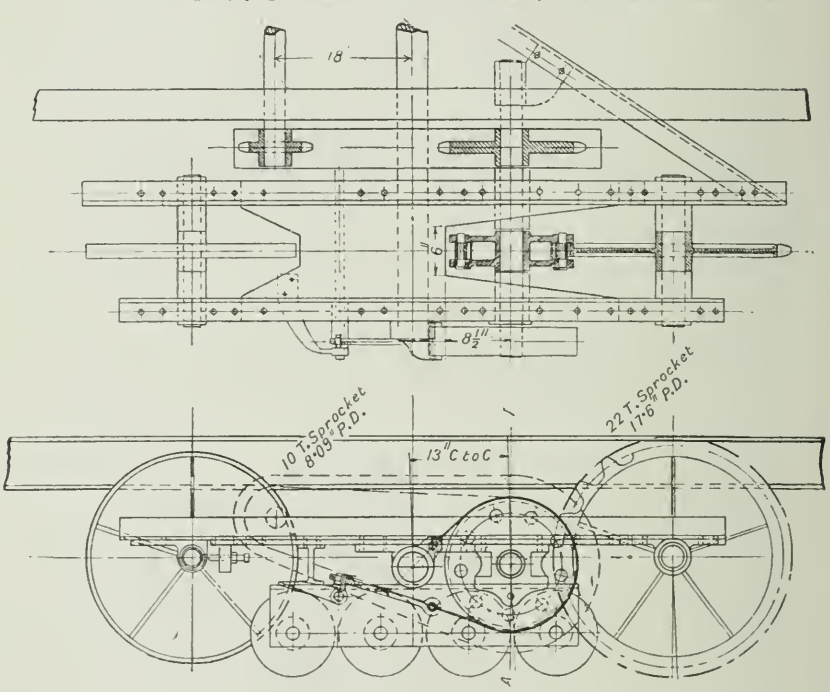
In both the 90 h.p., Fig. 101, Plate 19, and 75 h.p. Tracklayers the power is transmitted from the engine through an expanding clutch and flexible spring coupling to the transmission gear-box, which is of the usual sliding-gear type. There are two forward speeds and reverse. The gears are cut from steel, and the differential gears are fitted with brakes for assisting steering; the steering gear can be actuated by a power-driven worm-and-wheel device or by hand. Each differential bevel and brake drum is integral with the pinion, which drives into an internal gear also cast in one piece with the driving sprocket, Fig. 103, Plate 20; the sprockets revolve on a fixed axle about which the track-frame is pivoted. The front of each track is thus free to rise and fall independently of the other, according to the irregularities of the ground, and the effect is that of 3-point suspension. The upper portion of the chain is carried on three or two wheels respectively, to limit sagging. The actual construction of the chain differs from that of other track chains that have been mentioned, as it is fitted with a rocker joint, Fig. 55, Plate 8, somewhat similar to that in use on the Westinghouse-Morse noiseless drive chain. This design

FIG. 100.—*Clayton 35-h.p. Tractor; Elevation and Plan.*



is intended to work dry and to avoid the wear to which chains of the ordinary pin-joint construction are exposed when running in sand and grit. As in the other tractors described, an adjustment is provided at the front-end of the tracks for moving the idler-shaft bearings forward to take up wear.

FIG. 105.—*Creeping-grip, Senior; 50 h.p.; Detail of Track-Frame and Drive.*



In the 30 h.p., Fig. 102, Plate 20, and 16 h.p. Tracklayers there is no front wheel, the steering being effected by side-clutches of the expanding type. Power is transmitted through a disk-clutch to the gear-box. In the 30 h.p. this is fitted with two forward gears and a single reverse gear; in the 16 h.p. there are two speeds forward and the same in reverse. In both types the track-frames are pivoted about the back axle and carried, near the front idler,

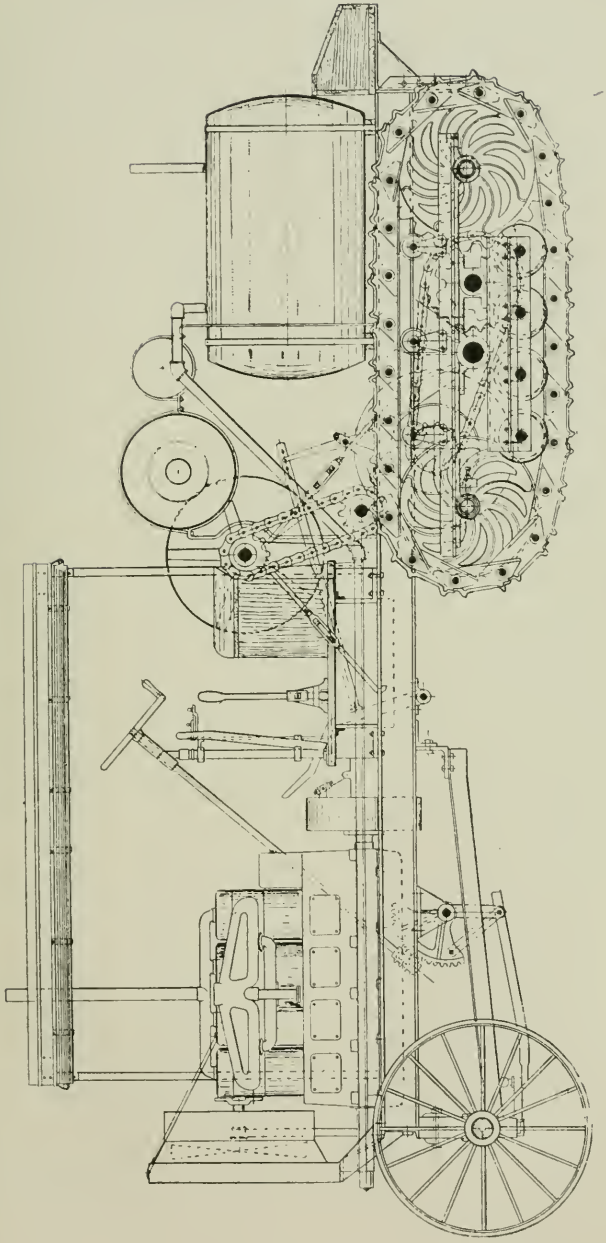


FIG. 106.

Creeping-grip, Senior; 50 h.p.; Side Elevation.

by helical springs bearing on the main frame. In the 30 h.p. the load is carried on four wheels, and in the 16 h.p. on three wheels; in both these types the upper part of the chain is supported by a single carrying wheel. An example of the Tracklayer at work is given in Fig. 104, Plate 20.

The Creeping-Grip Tractor, Bullock.

The chain-tracks in the Creeping-Grip tractors carry the tractor on wheels mounted on short axles fixed in the track-frame. The whole of each track-frame is pivoted about the axle, which passes through its centre, Figs. 105 and 106. This axle merely carries the track-frames. Power is transmitted from the gear-box to two pitch chains, which drive the two chain-sprockets; each of these is fixed to a short shaft running in bearings on the track-frame between the fixed axle and the sprocket; these shafts each carry a lantern wheel, which engages with the sprocket-wheel, the pins in the lantern wheel being of the same diameter as those in the chain-links, but the lantern wheel pins engage with each tooth of the sprocket, whereas the chain pins engage with the alternate teeth, Fig. 105.

In the 75 h.p. "Giant," and 50 h.p. "Senior," Fig. 107, Plate 21, models the weight is carried on four pairs of wheels in each truck; in the 30 h.p. "Junior," there are only three pairs of carrying wheels. The upper part of the chain is carried on three pairs of wheels in the two larger tractors and on one pair of wheels in the 30 h.p. model.

The gear-box is fitted with sliding dog-clutches, the gears being permanently in mesh; the differential gear is of the spur-wheel type. The motor of each model is governed.

The front axle of the 75 h.p. and 50 h.p. models has Ackermann steering and a centrally pivoted leaf spring which bears on the two axle ends and supports the front of the tractor in the centre; the arrangement, which is similar to that of the Centiped (Phœnix), gives 3-point suspension.

The 30 h.p. model has a single front steering wheel carried in a forked frame and controlled by a worm and wheel gear.

The small 16 h.p. "Baby," Fig. 108, Plate 21, has no front wheel, and is controlled by independent clutching of the two chain-tracks; it is possible to reverse either track independently for turning a circle of small radius. Details of the truck and of the track and wheels are shown in Figs. 110 and 111, Plate 22.

An example of the 16 h.p. Creeping-Grip at work is given in Fig. 109, Plate 21.

The Austin Tractors.

The F. C. Austin Drainage Excavator Co. of Chicago are makers of two models of chain track-tractors. The 35 h.p. tractor, Fig. 112, Plate 22, like most American low-power tractors is steered by declutching the tracks. This model is supported on six pairs of wheels to each track, which has a normal width of 12 inches, but the shoes, which are formed of flat plate with two corrugations, can be widened by bolting to them 36-inch treads of wood reinforced with steel plate; the insistent weight can thus be reduced from 4·7 lb. per square inch to 1·78 lb. per square inch—the lowest figure given in Table 2. The arrangement obtained by bolting wide treads to the shoes is liable to the disadvantage of damage, or jamming by stones or sticks due to nut-cracker action; generally tractors working with very low insistent weight are used for cultivating swampy land on which stones do not exist.

The 15 h.p. Austin tractor, Fig. 113, Plate 23, is very similar in construction to the larger model described, but is supported on two pairs of wheels only for each track; the insistent weight is 4·7 lb. per square inch, and the tractor can be used for hauling a gang of four disk-ploughs, ditching, road making or grading.

Burford-Cleveland Tractor.

The Burford-Cleveland tractor, Fig. 114, Plate 23, is of much lighter construction than the machines previously described, having been designed with a view to the exigencies of work in this country, where it is necessary that the headlands should be kept as small as possible. The tractor has no front wheel, steering being effected by brakes on each side of the differential, operated by the steering wheel.

The load is carried by three pairs of wheels, and the slack part of the chain is carried on a single wheel.

The engine is of the ordinary four-cylinder type carried in the main-frame by three-point suspension. The exhaust is led through a sleeve jacket on the lower part of the induction-pipe; this allows the use of inferior fuel such as paraffin or creosote waste.

The front end of each track-frame is formed with a yoke encircling the track-chain, and is connected by links to the end of a cross-spring the centre of which is secured to the main-frame by U-bolts in the usual manner; the tracks can oscillate about the axis of the back-axle.

The Burford-Cleveland tractor is shown in Fig. 115, Plate 24, at work hauling two ploughs.

It is to be noted that in all the vehicles described of this class the torque applied to the sprockets, which tends to lift the front of the vehicle, has the further effect in cases where the track-frame is pivoted, as in the Tracklayer and Creeping-Grip tractor, of increasing the insistent load on the front of the track itself.

The Strait Tractor, Killen-Strait.

This tractor, Fig. 119, Plate 26, presents several original features; the unsymmetrical driving track-frame, with its axle placed high and far back, carrying the driving sprocket over which the chain passes; the series of three pairs of large-diameter wheels under which the chain-track runs; and the spring arm which, by means of a helical tension spring, keeps the front of the track in contact with the ground.

The drawbar is attached to the frame by a swivel joint forward of the back axle, and it swings clear below the axle. The motor drives through a cone-clutch to the gear-box, which is of the sliding-gear type with reverse through bevel gears; the drive to the differential, which is of the bevel-gear type, is effected through spur gears; one driving sprocket is carried on a sleeve to which one bevel wheel is fixed, the other bevel wheel and sprocket being both keyed to the axle. The steering is operated by worm and

wheel fixed to a track-frame supported on a helical spring. This frame carries a miniature track of fifteen treads, Fig. 116, Plate 24. The load is carried through three pairs of wheels to the track-frame, Fig. 118, Plate 25; the front axle of these is adjustable for taking up wear. In climbing steep banks or in crossing ditches this front track is sometimes quite off the ground, behaving somewhat similarly to the leading wheel of the Clayton tractor, but with the difference that whereas in the Clayton tractor the track-frame is fixed and the whole movement taken by the front wheel, the movement in the Strait tractor is partially taken up by the spring on the front track column and partially by the springs that control the rocking action of the driving-tracks.

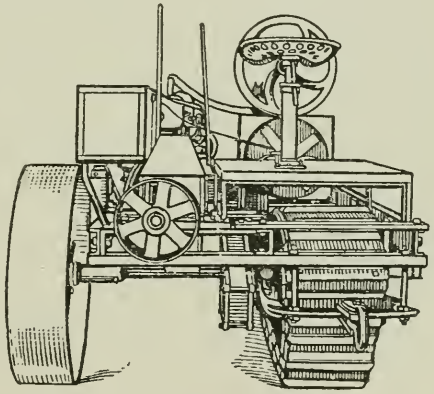


FIG. 123.

Strait Tractor; Model 3; End View.

In the Strait model 3 tractor, Fig. 122, Plate 27, the power is applied to a single chain-track at one side of the vehicle; this track is of similar construction to that of the ordinary model just described. The steering track carried in front is also similar to that already described both in form and in spring suspension, but it travels in the same path as the driving track. The engine is carried to one side of the main or driving track, and the machine is supported on the extreme left by a wide carrying wheel or roller, which runs freely, but can be adjusted laterally on its spring-supported axle, Fig. 123.

The gear-box is fitted with a single gear and reverse, but the engine speed is made variable, as in the ordinary motor lorry.

Examples of work performed by the Strait tractor are given in Figs. 120 and 121, Plates 26 and 27, and the model 3 is shown in Fig. 117, Plate 25 on deep ploughing.

The arrangement of the draw-bar attachment in the Strait tractors is kept low and forward so as to increase the load on the front of the tractor when hauling and consequently to gain adhesion.

The Ball-Tread Tractor, Yuba.

In this form of tractor, Fig. 124, Plate 28, the weight is distributed over the chain-track by two rows of steel balls 2·25 inches diameter, and is carried on ball races of annealed cast steel, built into the track-frames. The ball-race sections carried on the shoes are of L-form; those on the track-frame are, in section, of the form of a circular arc. Thus each ball bears against two faces at right angles to each other on the shoe and against the appropriate portion of the curved section of the track race, Figs. 127 and 128, Plate 29; it is claimed that this method of carrying the side-thrust renders the arrangement peculiarly suitable for use on side-lying ground. The ball races are kept supplied with heavy lubricating oil when at work.

The track-frames are pivoted about the rear axle, which also carries the driving sprockets; the front of each track-frame is connected, by compression springs, with a bracket carried on the main-frame. The driving sprockets are each formed with an internal spur-gear, into which gears the pinion carried on the corresponding cross-shaft of the gear-box. The clutch gear is such that the drive to each track, Fig. 129, Plate 29, can be reversed independently, enabling the machine to be turned in about its own length. The transmission gear is fitted with roller bearings for taking radial loads, and with ball-bearings for axial loads. The gear-box is arranged with two speeds forward, and the same for reverse.

Steering is operated by wire-rope connexions from the steering-wheel shaft to the front wheel frame, which runs on ball-bearings. An example of the climbing power of this tractor is shown in Fig. 132, Plate 31.

The speed changes are controlled from the operator's seat, and there is a foot accelerator for the motor.

Examples of the Ball-Tread tractor travelling on side-lying ground and at work are shown in Figs. 126, 130, 131 and 132–136, Plates 28 and 30–32.

MARTIN'S AGRICULTURAL TRACTOR.

This is a vehicle of lower power than the majority of those described above; it has been designed with the object of meeting British rather than Overseas conditions. Each track-chain passes round two idlers on the track-frame and over the track-sprocket carried on the main cross-shaft, Fig. 137, Plate 33. Either sprocket wheel or both can be engaged with the cross-shaft by means of dog-clutches. The tracks are arranged at the front of the machine, which weighs about 30 cwt. including the three-furrow plough.

Steering can be effected by a single central wheel, carried in a castor frame, for use when ploughing, or by a pair of steering wheels mounted in a carriage and operated by means of a pinion and quadrant, Fig. 138, Plate 33.

Examples of the Martin tractor at work are given in Figs. 139 to 141, Plates 33 and 34.

THE WOLSELEY MOTOR-SLEIGH.

This vehicle, Fig. 142 (page 128) and Fig. 143 to 146, Plates 34 and 35, was designed and built for Captain Scott's Antarctic expedition in 1909; three of these motor-sleighs were made with the object of facilitating transport over snow and ice.

A previous attempt was made by Mr. B. Hamilton to design a vehicle to cross hummocky ice and lumpy snow and ice, but on test in the Alps it was not found to meet the conditions sufficiently well. The Wolseley machine was designed to work with chain-tracks and to form a motor-sleigh. The first vehicle, which was

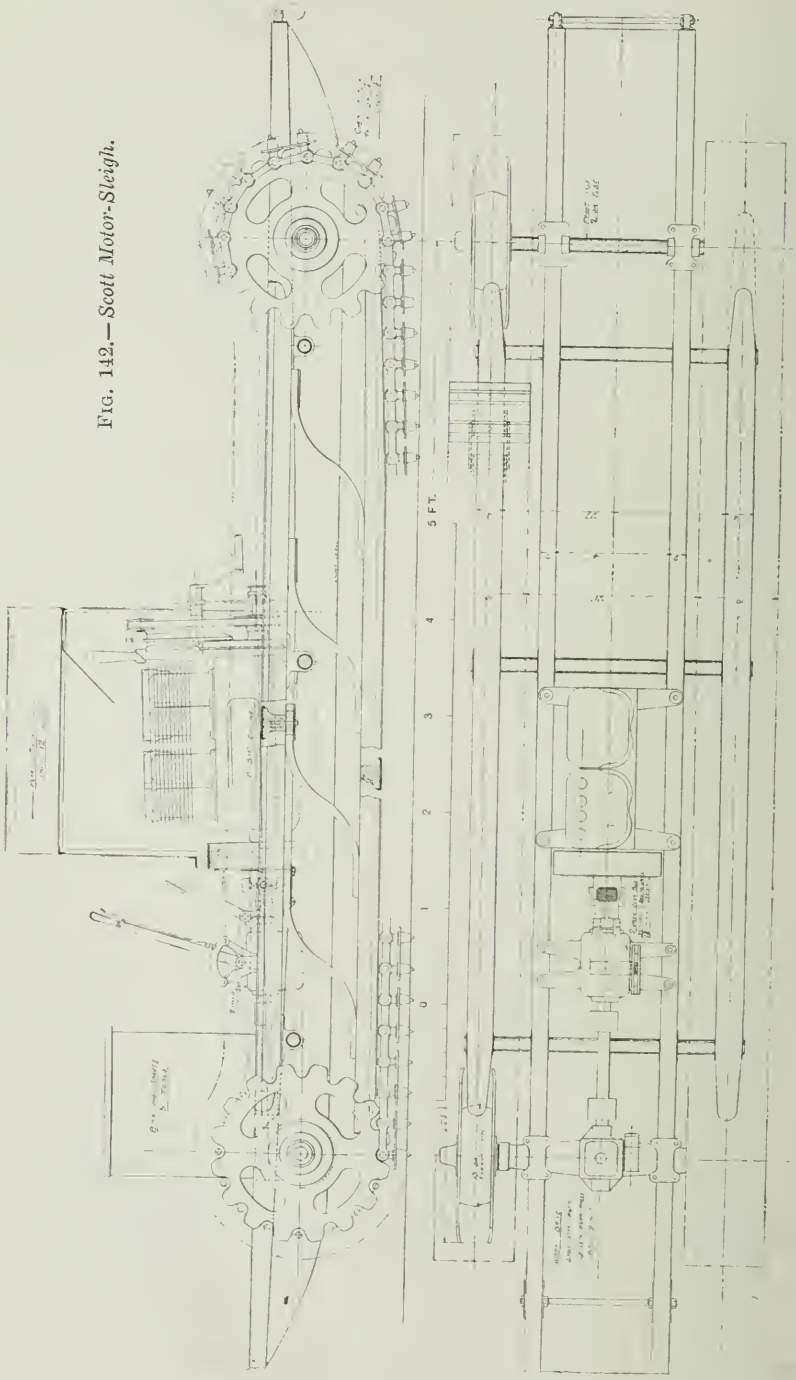


FIG. 142.—*Scott Motor-Sleigh.*

completed in February 1910, passed its tests satisfactorily on Lake Fefor in Norway, Fig. 146, Plate 35. The vehicles were used by Captain Scott, and rendered much assistance in the earlier stages of the expedition, but were left behind in the final dash for the South Pole.

The vehicle is remarkable in the arrangement of bearers which take the load; these are of wood, shod with sheet aluminium to avoid "snow-clogging." The chains were of soft steel links with wooden rollers. It is to be noted that the arrangement adopted differs from any of the other tractors described, as the rollers travel with and at the same speed as the chain, and the rollers also form the gearing surface with which the driving and idler sprockets engage. The heads of the bolts that secured the links to the chain-feet were made of pointed form, as shown in Fig. 142, so that the vehicle could travel equally well on smooth ice or over snow so loose that a man could only travel over it on skis. The engine was of 12 b.h.p., air-cooled, transmitting its power through a two-speed box to a differential-box and axle at the back end. The front axle carried two idlers. The speeds provided were 1·75 mile per hour on low gear and 3·5 miles per hour on top gear. In the trials made at the works it was found possible to drive the machine over loose ashes without scattering them in any way. The motor-sleigh was capable of climbing with ease a gradient of 1 in 2 (about 27°).

Mixed Tractors.

By mixed tractors are meant tractors in which the traction can be effected wholly or in part by chain-tracks, the load being carried on wheels; the only example of this class known to the Author is the Lefebvre tractor.

The Lefebvre Tractor.

This vehicle, Fig. 147, Plate 35, is designed to travel on wheels when running over the ordinary road, the tracks being raised out of contact with the ground.

The tracks are of a construction quite different from any of the heavy-weight carrying tracks previously described. In this instance light steel casehardened spade-plates of L-section are attached to

the pitch chains, each plate bridging 6 links of the chain. The spades present a vertical face to the ground, into which they cut when the chain is assisting the wheels. The aggregate surface so presented is that of 7 plates on each track measuring about 4 inches by 6·5 inches, giving a total area of about 360 square inches, available for propulsion on soft ground on which the wheels would not grip. These chains on each track are carried on a frame, pivoted about the rear or driving sprocket, which is not concentric with the axle of the back wheels, but placed at some distance behind the axle. A jockey pulley carried on the track-frame depresses the chain slightly in advance of the rear sprocket. Vertical guides with a power-operated screw-gear enable the track-frames to be depressed or raised through the full range in fifteen seconds under control of the driver. The adherence chains are so geared as to travel at the same linear speed as the periphery of the driving wheels, but a dog-clutch carried on the sprocket shaft enables the chain-drive to be disconnected when the chains are elevated and the tractor is running on hard ground.*

It is claimed that with the assistance of the adherence chains the tractive effort can be as much as 50 per cent of the weight of the vehicle.

Applications of Chain-Track Traction.

The following are examples of work done by chain-track tractors where roads are poor or absent, and heavy loads require to be moved:—

Timber.—80,000 feet of green rough timber hauled 15 miles over snow and ice track at a temperature of − 40° C.; the return journey of 15 miles without load but with empty sleighs. Water tank and caboose for crew are included in the load both ways.

Clay and gravel.—Hauling five to six wagons, loaded each with 6,000 lb. over heavy sand and over black land.

Ploughing virgin country; turning a 30-inch furrow 12 inches deep through scrub, Fig. 71, Plate 13.

* A description of this tractor is given in *Engineering*, vol. 101, pages 252–3.

Ploughing with five 14-inch ploughs to 8 inches depth, or with six 14-inch ploughs to 6 inches depth (45 h.p.).

Ploughing 40 acres per day (75 h.p.).

Ploughing partly drained marsh land.

Ploughing volcanic ash soil.

Ploughing a hill side.

Ploughing 16 inches deep in Texas Panhandle.

Ploughing 12 inches deep in black adobe.

Ploughing with a gang of 21 disk-ploughs.

Ploughing in sugar plantations, Cuba.

Ploughing 15 acres per day (35 h.p.).

Ploughing 100 inches wide by 7 inches deep in sandy loam (35 h.p.).

Rice farming; ploughing, harrowing and seeding. The chain-tracks enable irrigation ditches to be crossed; the tractors also haul harvesters and binders in the harvest season and do the work of ditching.

Ditching; hauling a ditcher for laying tile ditches, Fig. 82, Plate 16.

Road making and grading.

Hauling materials through desert sand for Los Angeles Aqueduct.

Clearing land for Catskill Aqueduct.

Hauling rock, ore, and road material.

Hauling load of 17 tons up a 20 per cent grade in Utah (75 h.p.).

Hauling load of 40 tons of rock across country for highway construction in California (75 h.p.).

Hauling piledriver in marshy land.

Hauling house weighing 50 tons $1\frac{1}{2}$ mile in forty-five minutes on dirt road, Fig. 120, Plate 26 (50 h.p.).

Hauling excavator.

Hauling scarifier.

Hauling sprayers.

Hauling harvester for 20-feet cut.

Hauling 8-feet double disk cultivator.

Hauling and operating hard-pan driller on fig plantation, California, for planting by dynamite, Fig. 133, Plate 31.

For all the above operations it is estimated that the cost of haulage by tractor is from one-third to one-half of that by horse or mule.

In the instances quoted a few only of the appliances hauled or operated are designed specially for use with chain-track tractors.

Chain-Track Haulage Wagons.

Where heavy loads have to be carried over sandy and boggy country or through wide shallow fords with soft bottom, it is possible to extend the principle to haulage wagons fitted with chain tracks; by this means a 100 h.p. tractor can haul a train of four wagons, weighing 5 tons each, and carrying a load of 10 tons each, or a total dead load of 60 tons and a paying load of 40 tons, over soft ground capable of supporting only 7 or 8 lb. per square inch.

Tractors hauling trains of chain-track wagons are shown in Figs. 148 and 149, Plate 36.

The Pedrail, fitted with an improved roller chain, Fig. 54 (page 95), arranged with two sets of rollers with axes at right angles to take vertical and horizontal loads respectively has been tried on a haulage wagon for stone, Figs. 150 and 151, Plate 36. The rolling friction is reduced by this arrangement to so small an amount that the vehicle will roll back on a 2 per cent slope.

Other Applications of the Chain-Track.

Trenching, ditching and farm drainage machines with chains of dredger buckets or excavating wheels are in many instances carried on and propelled by chain-track supports.*

Parsons Excavators.

The Parsons Company, of Newton, Iowa, make nine models

* Since this Paper was written a farm-drainage machine, with excavating wheel and chain-tracks, constructed by the Pawling and Harnischfeger Co., of Milwaukee, Wis., has been described and illustrated in *Engineering*, vol. 104, pp. 228 and 237–8.

of trench excavators; particulars of six of the larger models are given in Table 2 (pages 146–151).

The model 60 Trench Excavator, Fig. 152, Plate 37, is carried as to one-half of its weight on chain-tracks, the other half being distributed over pairs of leading and trailing wheels. The machine is steam-driven and comprises a conveyor for landing the spoil at an adequate distance from the trench.

The model 48 Trench Excavator is carried as to 75 per cent of its weight on chain-tracks, the remainder being carried on the leading wheels; the machine is driven by an internal-combustion motor of 62 h.p., and is illustrated in front-view in Fig. 153, Plate 37.

The model 24 Trench Excavator is of smaller size and fitted with a 30 h.p. motor; 71 per cent of its weight is carried on the chain-tracks and the remainder on the leading wheels. It is shown in back view in Fig. 154, Plate 38.

Of the other models one is entirely carried on chain-tracks, the steering being effected by clutches as in the smaller models of chain-track tractors (Burford-Cleveland, etc.).

Austin Drainage Excavators.

The F. C. Austin Drainage Excavator Company are makers of seven models of trenching or ditching machines capable of digging trenches from 6 feet to 25 feet deep, and from 15 inches to 72 inches wide. The rate of digging is stated to vary from 10 feet to 3 inches per minute.

The motors are from 18 h.p. to 85 h.p.; one of these machines is shown in Fig. 155, Plate 38.

The spoil can be delivered either to the right or left or to both sides of the machine as may be desired.

Another series of four models is constructed by the Austin Company and arranged for performing the further operation of bank-sloping for the sides of the trench either as a single operation, or by roughing and finishing operations. The wheel of the excavator, over which the chain of buckets passes, is formed of two truncated cones, arranged base-to-base, the conical surface being

represented by sloping cutter-bars capable of cutting away hard adobe soil. The wheels are constructed for various slopes of bank from $\frac{1}{2}$ to 1, to 1 to 1; the machines can be used for preliminary work in railroad construction, trenches being cut on each side of the land to be used, and the spoil from the two trenches conveyed to the middle of the strip where it is made up to formation level, bermes of the desired width being left on each side between the ditch and formation as shown in Fig. 156, Plate 39.

Those ditching machines which are intended to perform consecutive operations of trenching and bank-sloping have the chain-tracks arranged to straddle the trench; this necessitates great breadth of the machine which will measure as much as 14 feet 6 inches between the insides of the chain-tracks for cutting a ditch 10 feet wide at the top.

Applications of Trench Excavators.

These comprise: cutting trenches for sewers, water-mains, gas-mains, electric light and power cables, as well as work for street railways and railroad construction.

Back Fillers.

The land dredgers having cut the ditches or trenches at high speed to the required depth, and the sewers or mains having been laid, it is necessary to fill in the spoil again. For this purpose a different class of machine is used, which is virtually a locomotive crane also carried on chain-tracks. These machines are made by the constructors of trench-excavating machinery, and handle the spoil either with a clam-shell or grab bucket or with a drag-line bucket or a combination of the two for use alternatively. An example of a back-filler is shown in Fig. 157, Plate 39.

Further extensions of the use of the chain-track for carrying pile-driving machinery, as well as that used for road-making and for deepening channels in shallow streams may be expected in the future.

CONCLUSIONS.

In conclusion it can be safely said that where a track can be found seven feet wide which does not present rocky obstacles over ten inches high, whether over sand, ash, clay, marsh, snow or ice, on the level, or on gradients up to 30 per cent, the chain-track tractor has proved itself capable of travelling and performing useful work beyond the capacity of animal haulage.

For this reason the chain-track tractor may be expected to occupy a position of ever increasing importance in the development of new countries, and in places where it is necessary to transport machinery and stores over roadless country many miles from the railway.

The difficulties presented by the working conditions are such that the Author cannot regard any one of the existing systems as perfect, and expects that much will be done to improve the vehicles in the near future.

There is probably room for considerable improvement in the chain-track itself as well as in its supports and its anti-friction devices. The variation in resistance to haulage is so great as between one system and another, not merely in static resistance to starting, but in dynamic resistance to haulage, that, as already suggested, the various track systems should form the subject of comparative tests at some of the great agricultural colleges.

One feature that is particularly remarkable is the small amount of power lost in compressing soft marshy land under the feet of the track-chains. A very visible alteration of the appearance of a marshy surface due to the prints made by the track feet may, for example, only involve an expenditure of power which is but slightly greater than that required for hard ground, whereas the effort involved in walking over the same soft surface may be many times greater than that of walking on the hard road.

The Author desires, in conclusion, to express his thanks to Dr. William H. Maw, Past-President, I.Mech.E., to Mr. Coker F. Clarkson, General Manager of the Society of Automobile Engineers, to the Editor of *The Engineer*, to Col. R. E. B. Crompton, C.B., R.E., Dr. H. S. Hele-Shaw, and Messrs. W. Defries, W. F.

Rainforth, L. St. L. Pendred and G. W. Watson, MM. I.Mech.E., as well as to the Engineers, representatives, and agents of the firms manufacturing the vehicles described, for information on a subject which is at the present time very deficient in literature, for valuable assistance, and for very many of the photographs and drawings from which the illustrations for the Paper have been prepared.

The Paper is illustrated by 40 Plates, 50 Figs. in the letterpress, and is accompanied by 2 Appendixes with 4 Figs. and 2 Tables.

APPENDIX I.

Historical Note.

The use of multiple-wheel traction for road-tractors appears to have made its appearance in practical form almost simultaneously in France and Holland about 1903; in the latter country as the Spyker passenger car, and in the former as the Renard road-train. The idea of the road-train was taken up by the Daimler Co. of Coventry in 1907, and trains on this principle, embodying considerable improvements on the original French design, were tested in India. Apart from trials on comparatively flat country near Bombay, other and very severe trials were made on the Gauhati-Shillong road at the instance of the Indian State Railway. This road, which is about 64 miles in total length, with about seven miles level and a rise of nearly 5,000 feet in the remainder accompanied by the sharp curves and steep pitches of an ordinary cart road, was subsequently worked on the block system with single vehicles. The abandonment of the Renard train does not, however, appear to have been due to any failure to meet the conditions of traction.

An illustration of the complete Renard road-train is shown in Fig. 158, Plate 40, and the chassis are shown connected in plan in Fig. 159, Plate 40.

The vehicles were connected for traction by a coupling-bar which ensured the steering of the trailing vehicles; the power was transmitted from the locomotor by a cardan shaft, with a sliding joint in the coupling-section to permit of relative rise and fall of the vehicles.

There does not appear to have been either provision for compensating for varying velocities of the wheels of different vehicles, which could occur even with wheels of equal diameter on uneven surfaces, or provision of automatic locking devices for the differentials in case any driving wheel failed to grip. In such event the drive was taken by the other vehicles, but neither of the driving wheels of the vehicle in question could assist in traction under such circumstances.

It is worth noting that, in Young's work,* published in 1860, it is mentioned that a quarter-scale model made by Mr. Burstall of London in 1827, and tested at Edinburgh where it ran 250 miles in eight days, was arranged with a differential gear similar to that fitted to a steam coach by Rufus Porter of Hartford, Conn., about 1830. The date of Burstall's model is therefore earlier than the date of Roberts's invention previously given by the Author in a Paper on the "Development of Road Locomotion in Recent Years."† According to Young, the mitre gear arrangement of differential also appears in the subsequent American carriage of James about 1834. From this it would seem that the idea of the application of the balanced differential gear to traction originated in Britain, but was first applied to full size machines in the United States.

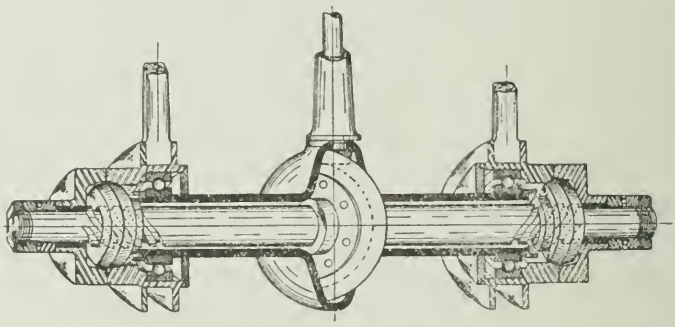
Difficulties with the bevel or spur forms of differential drive are familiar to all car drivers who have had experience with chain drives, particularly the difficulty caused by the fracture of a chain, which prevents driving except by the alternative of locking one sprocket and driving the other through the differential gear, with resultant doubling of the speed of the corresponding road-

* The Economy of Steam Power on Common Roads, page 351.

† Proceedings, I.Mech.E., 1910, page 1555.

wheel. To overcome this difficulty Hedgeland, of America, produced a solid axle with cone-clutches inside the wheel hubs, internally threaded, and carried on screwed portions of each end of the back axle, Fig. 160. The locking of one or other of these clutches with the corresponding wheel-hub permitted driving; overrunning of the wheel unscrewed the clutch and freed the wheel. On curves the work was consequently all thrown on to the inner wheel, or, if the wheels were of unequal diameter, on the straight the larger wheel alone became the driver; furthermore, if the brakes were applied or other change made in the drive, causing engagement of either or both of the clutches, appreciable shock resulted. It will be seen

FIG. 160.—*Hedgeland Axle.*

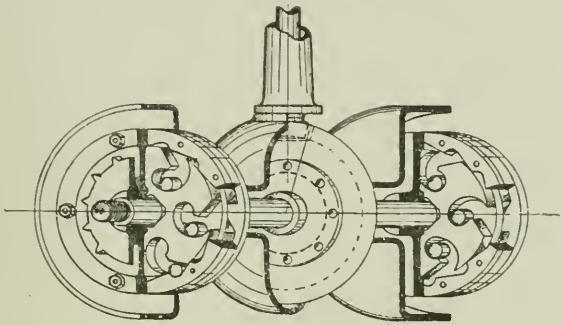


that with the Hedgeland axle the car would be driven by either back wheel on the straight at a speed corresponding to the normal mean revolutions which would be obtained with the ordinary type of differential, but that on a curve it would be driven faster than the normal.

This class of differential is therefore not a true differential, in the sense that it does not divide the power; but it is an arrangement equivalent to free-wheeling either road wheel in advance of the propelling gear. Several forms of cam and roller (derivatives of the Bourdon clutch) or eccentric gears have been devised for the same object, all of which are merely mechanical variants of the free wheel. Fig. 161 shows this device applied to

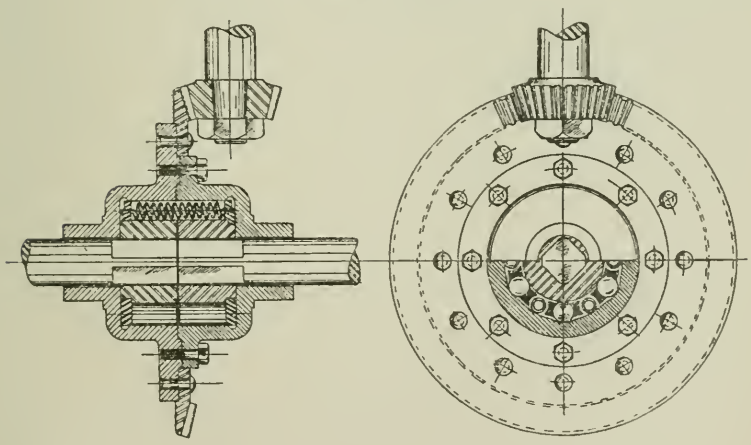
the hubs, and Fig. 162 shows it applied at the connexion of the axle-halves.

FIG. 161.—*Free-wheel Type Axle.*



Yet another form of differential is the eccentric and connecting-rod type, Fig. 163, in which each axle end is formed with two eccentrics with throws at right angles, and short connecting-rods

FIG. 162.—*Cam and Roller Type Axle.*

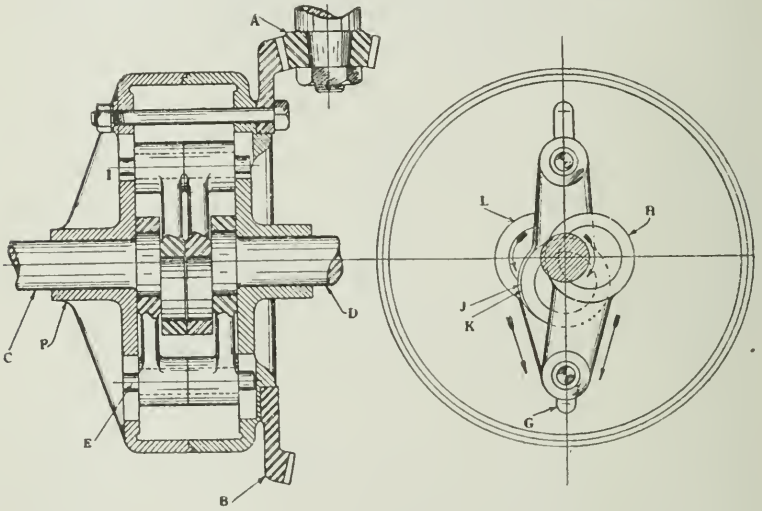


attached to these having gudgeon-pins common to each pair and sliding in slots in the differential casing. Thus in the illustration the short connecting-rods L and H are attached to the pin E, the

other pair J and K being attached to the pin I. It will be seen that the gear forms a balance-gear, the mechanical efficiency of which is reduced by friction in the eccentrics.

The subject has been dealt with very thoroughly under the title "Differential Substitutes" in a Paper read by Mr. D. D. Ormsby, before the Society of Automobile Engineers (America) in June 1916.* Mr. Ormsby points out that the trouble found with the ordinary differential is due to its being too efficient, and that it is possible to reduce the reversibility of the gear to any desired extent

FIG. 163.—*Eccentric and Connecting-Rod Type of Differential.*



by using suitably designed worm-gears. The illustrations of worm-differentials, Figs. 5 and 6 (pages 62–3), show that the backlash in angular movement of the wheel may be much less than was the case with the Hedgeland axle.

---

* Transactions of the Society of Automobile Engineers, vol. xi, 1916, Part II, pages 288–299.

The Author is indebted to this Paper for the illustrations of the Hedgeland free wheel, cam and roller clutch, eccentric and M & S worm differentials. Like Mr. Ormsby the Author has not come across an example, in practice, of the eccentric and connecting-rod gear shown in Fig. 163.

It was claimed for the Hedgeland gear that a car fitted with it was less liable to side-slip; the same claim is made for the worm differential gear, but the advantage of the worm differential, which has secured its adoption in one or other of its forms on the majority of four-wheel driven cars intended for use on bad roads or land, is the elimination of difficulty with mud-holes and ice-patches.*

The earliest chain-track invention of which any record has been traced by the Author is that of Richard Lovell Edgeworth of 1770.† In his description the inventor states that this "consists in making portable railways to wheel carriages, so that several pieces of wood are connected to the carriage, which it moves in regular succession in such manner that a sufficient length of railway is constantly at rest for the wheels to roll upon, and that when the wheels have nearly approached the extremity of this part of the railway their motion shall lay down a fresh length of rail in front, the weight of which in its descent shall assist in raising such part of the rail as the wheels have already passed over, and thus the pieces of wood which are taken up in the rear are in succession laid in the front, so as to furnish constantly a railway for the wheels to roll upon." If the word metal is substituted for wood, this description applies to the majority of the types of vehicles described in this Paper.

The next step is the invention of Thos. German in 1801, who placed a chain of rollers carried by linkwork between a runner, or sledge frame, carried on the vehicle, and the ground. This system, modified by the interposition of a chain-track resting on the ground, also has its modern analogues, of which the Log-Hauler and

---

* The makers of a model of four-wheel drive car quote the United States Government Specification No. 229 as being fulfilled by their gear, as follows:

"Differential; the differential shall be of such a type as to automatically permit the wheels to revolve at different speeds without complete loss of torque on either wheel, and also to apply at least normal torque to whichever wheel shall have traction. These requirements shall be met when the vehicle is running either forward or backward."

† Since this Paper was submitted to the Institution a series of articles on the "Evolution of the Chain-Track Tractor" has appeared in *The Engineer*, vol. 124, pp. 111–2, 134–6, 156–9, 181–4, 202–5, 221–4, and 241–4.

Centiped are the more important. The idea was revived in slightly different form by Wm. Palmer in 1812, and subsequently by Richard Barry in 1821.

In 1825 Sir George Cayley proposed a revolving railway with "the several links or parts . . . connected to each other by joints so formed as to limit the angular movement of any two of the said links relatively with each other by a stop." The form of construction shown in this inventor's drawings closely resembles that adopted on some of the earlier modern attempts to obtain a practical track-laying tractor; and, as has been shown, the chain proposed by him, with its limitation of angular movement, would have been subject to some of the disadvantages that retarded the recent development of this type of tractor in Britain.

The various attempts that were made to produce tractors in which the weight was distributed over a chain of rails or plates failed to evolve any practical device for nearly seventy years, when the less ambitious scheme, invented by Boydell in 1846, of a track-laying wheel, somewhat similar to the girdle wheels now in use for hauling heavy loads over soft land, was carried out in constructional form and actually subjected to severe tests on bad roads about 1858 to 1860. In this tractor the sections or feet were attached to the wheel by links.

Another system, making even less pretence to improvement in load distribution, was the Thomson loose rubber band creeping between the wheel centre and the track of tyre-shoes. In the earliest form the shoes were designed as a continuous chain girdle and later consisted of independent shoes. Road locomotives so fitted were adopted for the traction of road trains on the Grand Trunk road in India under the direction of Colonel R. E. B. Crompton.* The system had an active life of several years in the early seventies. The engines weighed about 9 tons, and hauled some 16 tons of load without undue road wear. The expense of maintaining the rubber tyres under these conditions was as low as 1·5*d*. per mile run. The invention constituted the first practical attempt to reduce the unsprung weight of the vehicle to that of the tyre-shoes alone.

* Proceedings, I.Mech.E., 1879, page 530.

In the latter half of the nineteenth century but few attempts to revive tracklaying tractors appear to have been made. At the Royal Agricultural Society's show, held at Kilburn in August 1879, two vehicles were exhibited by W. C. Pellatt of Clerkenwell.* These were fitted with self-laying continuous tracks of flat plates secured to chains; the jointing of the successive links was of the most primitive character with practically point contact between the chain links. The resultant wear would be sufficient to account for the failure of these vehicles to attain success although they again demonstrated the advantages of the chain-track for transport over soft ground.

The combination of the two ideas of the chain-track and the foot-spring in the same vehicle was developed by Diplock in his Pedrail alluded to by Dr. Hele-Shaw in a lecture given at Liverpool in 1903,† and in the discussion on Road Locomotion.‡ The diagram given by him, Fig. 40 (page 80), illustrates a further stage in the attempts to improve the springing of track-laying vehicles, a feature considered of but little importance in the earlier forms, but one the value of which is now being appreciated to an increasing extent by the manufacturers of chain-track tractors.

APPENDIX II.

Authorities Consulted.

Young, C. F. T. The Economy of Steam Power on Common Roads, London, 1860.

Proceedings of the Institution of Automobile Engineers.

Proceedings of the (American) Society of Automobile Engineers.

Proceedings of the Institution of Mechanical Engineers.

Engineering: The Engineer: The Autocar: The Implement and Machinery Review.

* *The Engineer*, vol. 47, page 124.

† "The Pedrail," a Revolution in Mechanical Locomotion. Lecture delivered to the Liverpool Self-propelled Traffic Association, by Prof. H. S. Hele-Shaw, at Liverpool University, 28 Nov. 1903.

‡ Proceedings, I.Mech.E. 1910, pages 1561-6.

TABLE 1 (*continued on opposite page*).

Four-Wheel Driven Vehicles.

—	Make and Description.	Normal Load.	Weight of Truck.	Total Weight.	Front and Back Wheels.	
		lb.	lb.	lb.	diam. in.	width. in.
1	FWD 1½-ton Model G	3,000	—	—	36	4
2	FWD 3-ton Model B 1915	6,000	6,000	12,000	36	6
3	FWD 5-6 ton	11,000	10,000	21,000	38	6 dual
4	Jeffery Quad Model 4016	4,000	*5,000*	*9,000*	36	5
5	Walter Super-quad 3-ton Model	6,000	*6,000*	*12,000*	40	6
6	Walter Super-quad 5-ton Model	10,000	*6,000*	*16,000*	40	7
7	Walter Super-quad Tractor	*6,000*	*6,000*	*12,000*	40	4 dual
8	Couple-Gear 3½-ton Petrol-Electric HC	7,000	*9,000*	*16,000*	36	3½ „
9	Couple-Gear 5-ton Petrol-Electric AC	10,000	*11,000*	*21,000*	36	4 „
10	Couple-Gear Electric 5-ton Model A	10,000	*11,000*	*21,000*	36	4 „
11	Couple-Gear Electric 3½-ton Model H	7,000	*9,000*	*16,000*	36	3½ „

Approximate or *estimated* figures are shown in italics.

Engine.

—	Make and Description.	H.P.	No. of Cylrs.	Bore.	Stroke.	1st Speed.
				in.	in.	gear ratio.
1	FWD 1½ ton Model G.	28·9	4	4½	5	—
2	FWD 3-ton Model B	36·1	4	4⅝	5½	35·6:1
3	FWD 5-6 ton	44·2	4	5¼	7	46:1
4	Jeffery Quad Model 4016	28·9	4	4¼	5½	42·3:1
5	Walter Super-Quad 3-ton Model	30·6	4	4⅜	6	67:1
6	Walter Super-Quad 5-ton Model	30·6	4	4⅜	6	67:1
7	Walter Super-Quad Tractor	30·6	4	4⅜	6	67:1
8	Couple-Gear 3½-ton Model HC	40	4	5	5½	25:1
9	Couple-Gear 5-ton Model AC	40	4	5	6	25:1
10	Couple-Gear Electric 5-ton Model A	18 h.p. battery of 44 cells 33 plates each				25:1
11	Couple-Gear Electric 3½-ton Model H	9 „ „ „ „		17 „	„	25:1

(*concluded from opposite page*) TABLE 1.

Four-Wheel Driven Vehicles.

Track.	Wheel base.	Turning Radius.	Width Overall.	Length Overall.	Platform Length.	Chassis Width Outside.	Clutch.
in.	in.	feet.	in.	ft. in.	ft. in.	in.	
56	124	46	—	16 8	11 4	36	multiple disk*
56	124	46	70	16 8	11 4	36	,,
72	148	34·5	88	21 8	13 0	—	,,
56	124	24	74	16 10½	10 0	38	disk
64	132	15	82	18 6	11 6	38	leather cone
64	156	17·5	82	20 6	15 0	38	,,
64	108	12·5	79	16 6	9 0	38	expansion cone
66	144	13·5	82	18 6	14 0	—	electric
66	144	13·5	89	18 6	14 0	—	,,
72	106	10	89	14 6	14 6	49	,,
66	106	10	80½	14 6	14 6	43	,,

* Hele-Shaw.

Speeds, Brakes, etc.

2nd Speed.	3rd Speed.	4th Speed.	Reverse Speed.	Foot-brakes. No. diam. Width.	Emergency brake. No. diam. Width.	Water. Galls. (Brit.)	Petrol. Galls. (Brit.)
gear ratio.	gear ratio.	gear ratio.	gear ratio.	No. in.	No. in.		
—	—*	—	—	8×1¾	13¼×2	—	—
17·8:1	8·9:1	—	36·1:1	10×3½	15½×2¾	6·6	21
22·5:1	12·1:1	—	55·3:1	10×4	15·9×4	—	21
24·7:1	14·05:1	8·5:1	45:1	4×6¾×2½	1×8×2½	9·2	22
27:1	13·6:1	8·4:1	51:1	2×12×4	1×10×3½	—	25
27:1	13·6:1	8·4:1	51:1	2×12×4	1×10×3½	—	25
27:1	13·6:1	8·4:1	51:1	2×12×4	1×10×3½	—	21
—	—	—	25:1	4×17×2	electric	—	17
—	—	—	25:1	4×17×2	,,	—	17
—	—	—	25:1	4×17×2	,,	—	—
—	—	—	25:1	4×17×2	,,	—	—

* Geared to 16 miles per hour.

TABLE 2 (*continued on opposite page*).

Chain-Track Tractors.

No.	Fig.	Pl.	Description.	Maker.	h.p.	No. of Cylinders.	Bore (in.).	Stroke (in.).
1	59	9	Log-Hauler (steam). . .	Phœnix	100	4	6·25	8·0 d.a.
2	66	11	Centiped . . . 50 h.p.	Phœnix	50	4	5·5	7·0
3	73	—	Tractor-Truck . Type A	Allis-Chalmers	68	4	5·25	7·0
4	74	13	Caterpillar . . 120 h.p.	Holt	120	6	7·5	8·0
5	75	14	Caterpillar . . 75 h.p.	Holt	75	4	7·5	8·0
6	76	14	Caterpillar . . 45 h.p.	Holt	45	4	6·0	7·0
7	78	15	Caterpillar . . 18 h.p.	Holt	18	4	4·5	6·0
8	92	18	Clayton Tractor . 110 h.p.	Clayton & Shuttleworth	110	6	5·75	6·5
9	100	—	Clayton Tractor . 35 h.p.	Clayton & Shuttleworth	35	4	4·75	5·5
10	101	19	Tracklayer . . 90 h.p.	C. L. Best	90	4	8·0	9·0
11	—	—	Tracklayer . . 75 h.p.	C. L. Best	75	4	7·75	9·0
12	102	20	Tracklayer . . 30 h.p.	C. L. Best	30	4	5·25	6·25
13	—	—	Tracklayer . . 16 h.p.	C. L. Best	16	4	4·375	5·25
14	—	—	Creeping-Grip . "Giant"	Bullock	75	4	7·5	9·0
15	107	21	Creeping-Grip . "Senior"	Bullock	50	4	6·5	8·0
16	—	—	Creeping-Grip . "Junior"	Bullock	30	4	5·0	7·0
17	108	21	Creeping-Grip . "Baby"	Bullock	16	2	6·0	6·0
18	112	22	Austin Tractor . . No. 35	F. C. Austin	35	4	5·0	6·5
19	113	23	Austin Tractor . . No. 15	F. C. Austin	15	4	4·25	5·5
20	114	23	Burford-Cleveland Tractor	H. G. Burford	20	4	3·5	5·125
21	119	26	Strait Tractor	Killen-Strait	50	4	4·75	6·75
22	119	26	Strait Tractor	Killen-Strait	50	4	4·75	6·75
23	122	27	Strait Tractor . Mod. 3	Killen-Strait	25	4	4·25	5·75
24	124	28	Yuba Tractor . Mod. 18	Yuba Ball-tread	35	4	5·25	5·75
25	124	28	Yuba Tractor . Mod. 12	Yuba Ball-tread	25	4	4·5	5·5
26	137	33	Martin Cultivator 25 h.p.	Martin	25	4	3·75	5·0
27	147	35	Lefebvre Tractor 40 h.p.	Lefebvre	40	4	5·125	6·25
28	—	—	Lefebvre Tractor 30 h.p.	Lefebvre	30	4	4·375	5·125
29	152	37	Trench Excavator (steam) . . . Mod. 60	Parsons	80	2	7·5	10·0 d.a.
30	153	37	Trench Excavator Mod. 48	Parsons	62	4	7·25	9·0
31	—	—	Trench Excavator Mod. 36	Parsons	45	4	6·25	8·0
32	154	38	Trench Excavator Mod. 24	Parsons	30	4	5·0	7·5
33	—	—	Trench Excavator Mod. 18	Parsons	20	4	5·0	6·0
34	—	—	Trench Excavator Mod. 15	Parsons	30	4	5·0	7·5

Approximate and *estimated* figures are shown in italics.

(*continued on next page*) TABLE 2.

Chain-Track Tractors.

No.	Rated r.p.m.	Main Clutch.	Speeds in m.p.h. at normal Engine revolutions.				Capacity: British Gallons.			
			1st.	2nd.	3rd.	Reverse.	Petrol.	Paraffin.	Bulk Oil.	Water.
1	—*	Throttle	0	to	5·0	0 to 5·0	—	—	—	—
2	700	—	1·5	3·0	5·5	1·5	—	50	—	—
3	1,000	Cone	1·61	3·5	6·2†	1·41	21	—	—	9
4	550	5 disk	2·13	(3·5)	—	2·13	—	53·5	5·0	67
5	550	5 disk	2·13	3·5	—	2·13	—	53·5	5·0	44
6	625	5 disk	1·5	2·13	3·5	1·5	—	36	—	7
7	750	3 disk	1·5	2·2	3·6	1·5	—	12	—	4·2
8	1,000	7 disk	1·25	3·5	5·0	2·0	2	12	5	12
9	1,000	Cone	2·0	4·0	—	1·75	2	12	—	5
10	450	Expanding	1·5	2·375	—	1·625	6	66	7	27
11	450	Expanding	1·5	2·375	—	1·625	6	66	7	27
12	600	Expanding	1·75	2·5	—	2·0	—	21	1·2	—
13	650	Expanding	1·75 to 2·38	—	—	1·75 to 2·38	—	12·5	—	—
14	550	Expanding	1·06	2·4	3·4	1·77	12	43	—	50
15	600	Expanding	1·06	2·4	3·4	1·77	12	46	—	120
16	600	Expanding	2·25	4·0	—	2·25 to 4·0	12	12	—	21
17	550	Expanding	2·5	—	—	2·5	12·5	—	—	—
18	800	—	1·25	2·5	3·75	1·25 to 3·75‡	16·7	33·3	—	47
19	800	—	1·25	2·5	3·75	1·25 to 3·75‡	7·5	15	—	11·7
20	1,000	2 disk	3·2	—	—	3·2	2	6	—	10
21	850	Cone	2·0	3·0	—	2·0	25	—	2·5	12·5
22	850	Cone	2·0	3·0	—	2·0	25	—	2·5	12·5
23	900	Cone	2·25	—	—	2·25	10	—	2·5	7
24	700	—	1·96	3·05	—	1·96	4·5	22·5	3·2	—
25	700	—	1·64	2·66	—	1·64	3	15	1·3	—
26	1,000	Cone	3·0	—	—	3·0	7·5	—	—	—
27	900	Disk	2·15	2·92	—	2·15	22	—	—	8·8
28	1.000	Disk	2·15	2·92	—	2·15	22	—	—	6·6
29	175*	Expanding	0·002 to 0·045		1·5	1·5	—	—	—	170
30	500	Band	0·004 to 0·055		1·375	1·375	43	—	—	170
31	600	Band	0·004 to 0·055		1·5	1·5	38	—	—	136
32	650	Band	0·008 to 0·110		1·5	1·5	27·5	—	—	89
33	700	Band	0·008 to 0·110		1·5	1·5	21·5	—	—	89
34	650	Band	—	—	1·5	1·5	27·5	—	—	89

* Steam. † 4th Speed 7·5. ‡ 3 Speeds on reverse.

TABLE 2 (*continued from previous page*).

Chain-Track Tractors.

No.	Fig.	Pl.	Description.	Maker.	Supports to each Track.	Track Width.	
						Normal.	Wide.
						in.	in.
1	59	9	Log-Hauler (steam) . .	Phœnix	14 rollers	12·0	—
2	66	11	Centiped . . 50 h.p.	Phœnix	14 rollers	12·0	—
3	73	—	Tractor-Truck . Type A	Allis-Chalmers	15 rollers	12·5	—
4	74	13	Caterpillar . . 120 h.p.	Holt	5 wheels	24·0	30·0
5	75	14	Caterpillar . . 75 h.p.	Holt	5 wheels	24·0	30·0
6	76	14	Caterpillar . . 45 h.p.	Holt	5 wheels	13·0	30·0
7	78	15	Caterpillar . . 18 h.p.	Holt	5 wheels	11·0	—
8	92	18	Clayton Tractor 110 h.p.	Clayton & Shuttleworth	7 wheels	22·5	—
9	100	—	Clayton Tractor . 35 h.p.	Clayton & Shuttleworth	4 wheels	14·0	—
10	101	19	Tracklayer . . 90 h.p.	C. L. Best	7 wheels	24·0	30·0
11	—	—	Tracklayer . . 75 h.p.	C. L. Best	5 wheels	24·0	30·0
12	102	20	Tracklayer . . 30 h.p.	C. L. Best	4 wheels	12·0	20·0
13	—	—	Tracklayer . . 16 h.p.	C. L. Best	3 wheels	10·0	—
14	—	—	Creeping-Grip . 75 h,p.	Bullock	4 wheels	20·0	—
15	107	21	Creeping-Grip . 50 h.p.	Bullock	4 wheels	20·0	—
16	—	—	Creeping-Grip . 30 h.p.	Bullock	3 wheels	12·0	—
17	108	21	Creeping-Grip . 16 h.p.	Bullock	3 wheels	12·0	—
18	112	22	Austin Tractor . 35 h.p.	F. C. Austin	6 wheels	12·0	36·0
19	113	23	Austin Tractor . 15 h.p.	F. C. Austin	2 wheels	12·0	—
20	114	23	Burford-Cleveland 20 h.p.	H. G. Burford	3 wheels	6·0	—
21	119	26	Strait Tractor . 50 h.p.	Killen-Strait	3 wheels	18·0	24·0
22	119	26	Strait Tractor . 50 h.p.	Killen-Strait	3 wheels	30·0	36·0
23	122	27	Strait Tractor . 25 h.p.	Killen-Strait	3 wheels	17·0	—
24	124	28	Yuba Tractor . . 35 h.p.	Yuba Ball-tread	2 × 21 balls	17·0	—
25	124	28	Yuba Tractor . . 25 h.p.	Yuba Ball-tread	2 × 16 balls	15·0	—
26	137	33	Martin Cultivator 25 h.p.	Martin	3 wheels	8·0	—
27	147	35	Lefebvre Tractor . 40 h.p.	Lefebvre	Not supporting	10·2	—
28	—	—	Lefebvre Tractor . 30 h.p.	Lefebvre	Not supporting	8·3	—
29	152	37	Trench Excavator Mod. 60	Parsons	6 wheels	26·0	—
30	153	37	Trench Excavator Mod. 48	Parsons	6 wheels	27·5	—
31	—	—	Trench Excavator Mod. 36	Parsons	6 wheels	26·0	—
32	154	38	Trench Excavator Mod. 24	Parsons	6 wheels	25·5	—
33	—	—	Trench Excavator Mod. 18	Parsons	6 wheels	24·0	—
34	—	—	Trench Excavator Mod. 15	Parsons	9 wheels	30·0	—

Approximate and *estimated* figures are shown in italics.

(*continued on next page*) TABLE 2.

Chain-Track Tractors.

No.	Track Length.	Area of Tracks.		Weights (lb.) carried on			Total Weights (lb.).		Insistent Weight in lb. per square inch.	
		Normal.	Wide.	Tracks.		Steering Wheels.				
	in.	sq. in.	sq. in.	Normal.	Wide.		Normal.	Wide.	Normal.	Wide.
1	60	1,440	—	30,500	—	5,500	36,000	—	21·18	—
2	60	1,440	—	13,600	—	3,200	16,800	—	9·45	—
3	60	1,500	—	*14,400*	—	*3,600*	18,000	—	*9·60*	—
4	80	3,840	4,800	23.750	—	2,500	26,250	—	6·19	4·95
5	80	3,840	4,800	21,350	—	2,250	23,600	—	5·56	4·45
6	70	2,080	4,800	13,000	14,500	—	13,000	14.500	6·25	3·02
7	64	1,408	—	6,000	—	—	6,000	—	4·26	—
8	100·5	4,522	—	26,880	—	3,360	30,240	—	5·94	—
9	71·3	2,000	—	5,040	—	—	5,040	—	2·52	—
10	90	4.320	5,400	*25,000*	*25,000*	*5,000*	*30,000*	*30,000*	*5·79*	*4·63*
11	66	3,168	3,960	*23,300*	*23,300*	*4,700*	*28,000*	*28,000*	*7·36*	*5·88*
12	66	1,584	2,640	8,500	8,500	—	8,500	8,500	5·37	3·22
13	66	1,320	—	5,100	—	—	5,100	—	3·86	—
14	64	2,560	—	19.500	—	3.500	23,000	—	7·62	—
15	64	2,560	—	*16,500*	—	*3,000*	*19,500*	—	*6·45*	—
16	48	1,152	—	*6,500*	—	*1.500*	*8,000*	—	*5·64*	—
17	48	1,152	—	5.200	—	—	5,200	—	4·51	—
18	96	2,300	6,900	10,800	12,300	—	10,800	12,300	4·70	1·78
19	60	1,440	—	6,750	—	—	6,750	—	4·70	—
20	50	600	—	3,000	—	—	3,000	—	5·00	—
21	48	1.728	2,304	*8.000*	*8.000*	*1,500*	9,500	*9,500*	4·63	*3·47*
22	48	2,880	3,456	*8,500*	*8,500*	*1,500*	*10,000*	10,000	*2·95*	2·46
23	48	816	—	*3,000*	—	*1,000*	6,000*	—	*3·68*	—
24	48	1,632	—	7,400	—	1.500	8,900	—	4·53	—
25	36	1,080	—	6,000	—	1,600	7,600	—	5·55	—
26	40	640	—	3,250	—	670†	3,920	—	5·01	—
27	63	—	—	—	—	4,000	7,050	—	—	—
28	51	—	—	—	—	1,780	5,950	—	—	—
29	72	3,744	—	27,000	—	27,000 ‡	54,000	—	7·21	—
30	72	3,960	—	33.800	—	11,200	45,000	—	8·54	—
31	66	3,432	—	22,000	—	8,000	30,000	—	6·41	—
32	62	3.162	—	12.000	—	5,000	17,000	—	3·80	—
33	41	1,968	—	7,000	—	2,600	9,600	—	3·56	—
34	78	4.680	—	20,000	—	—	20.000	—	4·27	—

* 2000 lb. on wheel. † On ploughs. ‡ Two pairs of wheels.

TABLE 2 (*continued from previous page*).

Chain-Track Tractors.

No.	Fig.	Pl.	Description.	Maker.	Steering gear.
1	59	9	Log-Hauler (steam) . .	Phœnix	Runners and engines
2	66	11	Centiped . . 50 h.p.	Phœnix	Front wheels
3	73	—	Tractor-Truck . Type A	Allis Chalmers	Front wheels
4	74	13	Caterpillar . . 120 h.p.	Holt	Front wheel and clutches
5	75	14	Caterpillar . . 75 h.p.	Holt	Front wheel and clutches
6	76	14	Caterpillar . . 45 h.p.	Holt	Clutches and brakes
7	78	15	Caterpillar . . 18 h.p.	Holt	Clutches
8	92	18*	Clayton Tractor 110 h.p.	Clayton & Shuttleworth	Front wheel and brakes
9	100	—	Clayton Tractor 35 h.p.	Clayton & Shuttleworth	Clutches and brakes
10	101	19	Tracklayer . . 90 h.p.	C. L. Best	Front wheel and clutches
11	—	—	Tracklayer . . 75 h.p.	C. L. Best	Front wheel
12	102	20	Tracklayer . . 30 h.p.	C. L. Best	Clutches and brakes
13	—	—	Tracklayer . . 16 h.p.	C. L. Best	Clutches and brakes
14	—	—	Creeping-Grip . 75 h.p.	Bullock	Front wheels
15	107	21	Creeping-Grip . 50 h.p.	Bullock	Front wheels
16	—	—	Creeping-Grip . 30 h.p.	Bullock	Front wheel
17	108	21	Creeping-Grip . 16 h.p.	Bullock	Clutches*
18	112	22	Austin Tractor . 35 h.p.	F. C. Austin	Clutches and brakes
19	113	23	Austin Tractor . 15 h.p.	F. C. Austin	Clutches and brakes
20	114	23	Burford-Cleveland 20 h.p.	H. G. Burford	Band brakes
21	119	26	Strait Tractor . 50 h.p.	Killen-Strait	Front track
22	119	26	Strait Tractor . 50 h.p.	Killen-Strait	Front track
23	122	27	Strait Tractor . 25 h.p	Killen-Strait	Front track
24	124	28	Yuba Tractor . 35 h.p.	Yuba Ball-tread	Front wheel*
25	124	28	Yuba Tractor . 25 h.p.	Yuba Ball-tread	Front wheel*
26	137	33	Martin Cultivator 25 h.p.	Martin	Dog clutches.
27	147	35	Lefebvre Tractor 40 h.p.	Lefebvre	Front wheels
28	—	—	Lefebvre Tractor 30 h.p.	Lefebvre	Front wheel
29	152	37	Trench Excavator Mod. 60	Parsons	Front and back wheels
30	153	37	Trench Excavator Mod. 48	Parsons	Front wheels
31	—	—	Trench Excavator Mod. 36	Parsons	Front wheels
32	154	38	Trench Excavator Mod. 24	Parsons	Front wheels
33	—	—	Trench Excavator Mod. 18	Parsons	Front wheels
34	—	—	Trench Excavator Mod. 15	Parsons	Clutches.

Approximate and *estimated* figures in italics. * Either track can be reversed.

(*concluded from opposite page*) TABLE 2.

Chain-Track Tractors.

No.	Tractor overall. Normal width.	Tractor overall. Length.	Turning radius.	Drawbar pull on low gear.	Front Wheels. No.	Front Wheels. Width.	Front Wheels. Dia.	Pitch of chain-track.	Drawbar pull. Per cent of weight. Normal.	Drawbar pull. Per cent of weight. Wide.
	ft. in.	ft. in.	ft. in.	lb.		in.	in.	in.		
1	5 4	27 6	75 0	—	2	runners		*9·5*	—	—
2	5 4	21 0	25 0	8,000	2	10	40	*9·5*	47·6	—
3	*5 6*	*21 6*	*26 0*	8,000	2	10	40	7·6	44·4	—
4	8 8	21 0	*16 0*	12,000	1	18	36	*9·25*	45·7	—
5	8 8	19 6	15 0	8,500	1	18	36	*9·25*	36·0	—
6	6 8	12 9	6 0	4,500	none	—	—	*9·25*	34·6	31·0
7	4 3	9 6	6 0	2,800	none	—	—	*7·5*	46·7	—
8	7 4	17 6	10 0	22,000	1	6	50	7·75	72·8	—
9	5 4	10 10	7 0	—	none	—	—	7·5	—	—
10	*8 9*	*24 6*	—	14,500	1	20	40	9·75	48·3	—
11	8 7	22 4	—	12,000	1	24	48	9·75	42·9	—
12	5 5	9 4	6 0	3,500	none	—	—	7·25	41·2	—
13	4 2	7 0	5 0	1,750	none	—	—	4·6	34·3	—
14	8 0	18 8	30 0	13,000	2	10	40	9·0	56·5	—
15	8 0	18 0	30 0	8,200	2	10	40	*9·0*	42·1	—
16	5 8	13 0	22 0	3,330	1	14	32	*7·0*	41·6	—
17	5 3	11 6	8 0	—	none	—	—	*6·0*	*30·6*	—
18	5 8	10 0	6 0	5,400	none	—	—	*9·0*	50·0	43·9
19	6 0	9 0	6 0	3,000	none	—	—	*9·0*	44·4	—
20	4 2	8 0	6 0	*2,000*	none	—	—	8·0	*66·7*	—
21	6 0	13 0	8 0	5,600	1	14	chain track	6·5	59·0	*59·0*
22	8 0	13 0	8 0	5,600	1	14	chain track	6·5	*56·0*	56·0
23	5 10	12 10	8 0	*2,500*	1	12	chain track	6·5	41·7	—
24	6 1	15 1	7 6	4,600	1	14	36	*3·75*	51·7	—
25	5 9	14 7	7 9	3,400	1	14	36	*3·75*	44·7	—
26	4 6	16 0†	8 0	*1,900*	none	—	—	7·0	48·5	—
27	6 1	18 0	16 6	4,400	2	10	30	8·5	62·4	—
28	5 9	15 8	11 6	3,100	1	14	30	8·5	52·0	—
29	10 0	35 0	30 0	—	2‡	14	40	7·0	—	—
30	10 5	46 6	50 0	—	2	20	40	6·0	—	—
31	8 9	36 6	50 0	—	2	20	34	6·0	—	—
32	7 8	28 3	30 0	—	2	15	30	6·6	—	—
33	7 0	23 0	30 0	—	2	15	26	5·0	—	—
34	10 0	15 0	30 0	—	none	—	—	6·0	—	—

† Includes ploughs. ‡ Also two back wheels.

Discussion.

Mr. H. G. BURFORD wished to congratulate Mr. Legros on the very excellent Paper or Lecture which he had delivered at the last Meeting. The general question relating to road traction and the points of historical interest in the Paper had been dealt with many times, both before this Institution and before the Institution of Automobile Engineers. Referring first to Part I of the Paper, one of the interesting features was the detail given of the four-wheel drive. This drive, as far as its use for commercial purposes in this country was concerned, had been developed rapidly since the country had been engaged in war. In his opinion, however, the commercial usefulness of the four-wheel drive was very limited in settled countries such as Great Britain, but there was certainly a very large field for it in new countries where roads were not as good as they were here.

The Author had not pointed out, as he could well have done from his large experience, the principal features that engineers should have in mind when designing and constructing a commercial vehicle to meet modern requirements. From his own experience he much preferred a machine or commercial vehicle built on the unit principle—for example, the engine and transmission as one unit, the rear axle and differential as another unit, frame and springs another, front axle and steering another—so that each unit was self-contained. This greatly reduced the cost of operation. Instead of the usual repairing of any part on the chassis, where large quantities of vehicles were employed, new units could be put in immediately for replacement. The great question in connexion with commercial use was that of interchangeability. The Author had given a historical review of the various types, but he might have laid more emphasis on the question of reliability, interchangeability, and the principles of design which would enable quick and cheap replacements.

Mr. Legros had also drawn attention to the question of various methods of locking the differential gear. From his own past 18 years' experience of ordinary commercial cars, nearly all the designs he had studied and worked had been of very little practical use, the reason being that if an ordinary back-wheel drive got into a position in which it could not be got out with one wheel, it was equally hopeless when the other wheel was locked. He respected the Author's authority on motor traction in every way, having known him for nearly 22 years in connexion with the movement, and he endorsed very fully his remarks on that subject—that some intelligent investigation was required on some points and particularly the locking of differentials, and this might well receive the support of the Institution.

Another question relating to commercial vehicles, which had been discussed both in this country and in America, was the final drive or final form of transmission. Apparently this had developed under two heads:—(1) the worm drive, and (2) the internal pinion or rack and pinion. In studying the development of the industry in America, it was really remarkable to note the progress that internal gear-driven machines had made in that country. From his own experience he had always been, and still was, a very strong advocate of the internal rack and pinion drive as against the worm drive which was so common in this country.

With regard to braking, the Author gave some information as to the application of brakes to commercial vehicles, and suggested that four wheels could be used for braking instead of the usual practice of braking on the two rear-wheels. Admitting that the efficiency would be higher, he thought the steering, the cost of manufacture, and the many difficulties which surrounded the application of front-wheel brakes, would not justify the expense incurred. Further, having regard to the general improvement in motor driving in this country, and the fact that the average person had a better idea of speed than formerly—and, after all, it was a question of speed and judgment—he thought the ordinary commercial vehicle was doing quite well with the back-wheel brakes as now used.

(Mr. H. G. Burford.)

In his opinion Part II was the most interesting part of the Paper. It set out in detail the various forms of chain-track in use, whether actually of chain-driven types, pedrails or other designs, apart from the ordinary wheel-driven machines. It was probable that the war, more than anything else, had brought into prominence the application of the chain-track to the "Tanks" more than would have been the case in two or three hundred years of peace. Various types of machines had been put forward by the Author for consideration, but he would like to have had some guidance from an expert, a gentleman who had studied the question very carefully and closely, as to the best means of control, the best means of steering, and the approximate weight he would consider with the appropriate width of track to satisfy the agricultural interests of this country. At the moment the agricultural question was uppermost in most men's minds, seeing that we now had to rely so much in this country on agriculture for our daily bread. The value of the Paper and of Papers of a similar description would be considerably increased if they could assimilate the experience of engineers who had already manufactured various types of vehicles. If it were possible for the Author to read a Paper dealing with the subject of why various types of vehicles or tractors had become obsolete, and why they were discarded, whether on the grounds of cost of manufacture or on the ground of inaccessibility or for any other reason, it would be of great value. Of course it would cost considerable research and money. The reason why he suggested that was because it would save so much of the time of young engineers and firms who were entering the engineering business of manufacturing, if they could ascertain why such and such a thing had failed—whether it failed from constructional defects, faulty material or from the wear and tear of actual use. If a Paper of that kind were published in the Proceedings of the Institution, the world generally, and engineers in particular, would have a good starting point that would be helpful in the future.

Colonel R. E. B. Crompton, C.B., R.E. (T.), said he rose with great pleasure to say a few words on the Paper, for which he felt

partly responsible, as he believed the idea of it originated when Mr. Legros was working with him on a very important national matter connected with the subject, of which they were not now allowed to speak. To his mind the value of the Paper lay in drawing attention to the importance of applying mechanical power to haulage purposes in situations off the highways, situations such as were familiar on the war front in a greatly accentuated degree; for it could hardly be called ground that the vehicles had to travel over; it resembled more a morass in a partly liquid form. These difficult requirements had undoubtedly stimulated invention, and improved design would be a means of meeting the smaller difficulties of the same class which the farmer encountered when he utilized mechanical haulage for ploughing his land or for removing his produce from fields without over-compressing or damaging its surface. He congratulated the Institution on having received from the Author such a valuable compilation of what had already been done, as it could not fail to be of great use to designers who were now engaged on this work. Whether it could be further supplemented, as Mr. Burford had suggested, he very much doubted, for however desirable, it would be a long and difficult task; but whether supplemented or not, the Paper was an extremely valuable one.

As an old man, who had bridged a good span of life, he wished to try to do justice to those who had worked on this problem in the past. It was probably forgotten by many of the members that he himself had read a Paper before the Institution on Thomson's road engines,* used by him in India for traversing soft ground; this was thirty-nine years ago, and he had still a good many copies left, because during the twenty years which followed that Paper the whole matter, which was then thoroughly developed and in a fair way to do what was being done now, went to sleep on account of the determined opposition, not of the road authorities but of railway companies, who thought that the railway and its development, either as light railways or tramways, was the only way of extending the locomotion of a country. Everyone knew now what a mistake that

* Proceedings, I.Mech.E., 1879, page 494.

(Col. R. E. B. Crompton.)

had been, and it could be seen how completely any system of railways, not supplemented by a system of road carriage, failed to develop the farming interest of a country, failed to distribute its food, and had now brought it to the brink of famine. When in the Army as a mechanical engineer with a turn for studying road locomotion, having constructed vehicles of his own with his own hands, he was sent home by the Government of India, and entrusted with a considerable grant of money to purchase and work the late R. W. Thomson's great invention of road steamers. Road steamers were connoted with the invention of rubber tyres, first with the then little known pneumatic pattern, which, on account of difficulties of manufacture, did not at first develop, but by his successful development of driving wheels with large flat surfaces on the ground, thereby extending their surface and enormously increasing the tractive power of the tractor. He was sent home from India with the object of developing these engines, so that they could be used in India for carriage on the existing roads and across open country, and so do away with the necessity for the extension of light railways for collecting crops. These vehicles could be used in one part of the country for one season of the year, and might be transferred to another part of the country at another time of the year, which was peculiar to all systems of road transport. He found Mr. Thomson the mechanical genius of his time—1870. His chief draughtsman and designer was the present Sir Alexander Kennedy, and he believed that Sir Alexander Kennedy, Mr. Richard Muirhead, and himself were probably the only people alive now who saw much of or had the privilege of enjoying conversations with R. W. Thomson. R. W. Thomson foresaw everything, indeed much that was foreshadowed in Mr. Legros's Paper—the Boydell girdle, which has been adopted by the Germans and by ourselves for guns in this war; the further development of various forms of chains, in Thomson's case, encircling the rubber tyre were all discussed and many of the difficult points that Mr. Legros had so ably brought forward were foreseen by Thomson. He was sure that Sir Alexander Kennedy would agree with him in that.

All those who had worked on the "caterpillar" problem, in order

to get a very extended flat foot in contact with the ground, knew that the principal wear took place at two points, at the pin-joints where there was the greatest angular motion, that is, at the point where the chain came down from the leading wheel on to the ground surface. There was little motion on the pin during the time it was passing over the flat surface of the ground, but when it was lifted up at the back of the track there was another large angular motion on the pin, and all experience had been to go back as nearly as possible to the original wheel, that was, to make both the front wheel and back wheels of the tracks of very large diameter.

He was not able to say very much on this subject, because it was closely connected with developments in the Field. The limitation of angular pin movement was one of the things to which attention had to be directed. It was necessary to get the happy mean between a short track with a short flat foot, which was almost the same as a very large wheel, and the other extreme, the very long track with a very large angular movement at each end.

Then came the second difficulty, that of taking up the slack due to the chain wear at the pin-joints. Thomson produced his flat foot by a very thick rubber tyre which practically gave an endless chain; of course, this was really supplying an infinity of pin-joints within the rubber itself, and which he thought would not wear or give any trouble, but unfortunately internal wear took place in the rubber; what electrical engineers called hysteresis took place—that resistance to internal molecular motion which was developed as heat at points of acute flexure and destroyed the rubber. The same thing occurred every day in motor-'bus tyres; owners of those vehicles had recently called upon him to take up the matter so as to tell them all that happened when they use a material like rubber to take the place of a mechanical chain. A Committee had been appointed to deal with it after the war.

In Thomson's case the flat foot was obtained by an enormous expenditure on rubber, his tyres being $4\frac{1}{2}$ inches thick, and the rubber was found to wear on both surfaces. On the interior surface the wheel slipped inside the rubber and abraded that surface. Mr. Legros had mentioned the reason, which was that some slipping had to take

(Col. R. E. B. Crompton.)
place at that point instead of the differential, thus allowing a friction-clutch inside the rubber tyre. This was an expensive mistake, and had to be abandoned. The outside of the rubber tyre was discovered to have a very low coefficient of adhesion in certain conditions, such as greasy surfaces of land or road, and it was necessary to supplement it with a steel chain on the outside. Then at once came the "caterpillar" difficulties, the perpetual stretching and lengthening of the chains due to the wear of the pin-joints. They became so slack that they had to be shortened on the road, and it was necessary to carry an arrangement of cramps and mechanism for clipping them up and cutting out a length and joining them together again. As he was one of the men who were developing the thing, he was one of those who came in for much of the abuse. To-day it was possible to do a great deal better in the utilization of chains, owing to the wonderful development of roller chains by various makers, such as those by Hans Renold, the Coventry Chain Company, and others. The magnificent workmanship rendered possible by automatic tools allowed roller chains to be turned out of the very highest class of material, case-hardened all over, and with very small play to allow mud and dirt to get in. This was very hopeful. Now that the "caterpillar" makers had had the advantage of the knowledge of these things, it was hoped that by sheer good workmanship a great deal of the troubles experienced in the use of those kinds of chains in those early days would be avoided. He had touched on a good many of the points, and what he wished to impress upon the members was that there never was a time when a mechanical engineer who had in him the art of design could address himself to a more worthy object than the production of a thoroughly efficient, well-conceived tractor that the British farmer could use on his land or for bringing his produce off the fields to market. In justice to Mr. Burford, he ought to say that he was glad to find that one of the finest designs that he had seen of that kind was by Mr. Rollin White, the inventor and developer of the White steam-car, who was well known as a real mechanical genius. His ploughing tractor, which he had examined, was the most beautiful example of simplicity and brilliant ideas brought

together and worthy of study. If the other forms of ploughing tractors mentioned in the Paper were anything like Mr. White's, he congratulated the world on the progress that it had made in mechanical design as applied to so worthy an object.

Mr. George Watson said, with regard to Mr. Legros' Paper, he did not think his friend Mr. Burford quite allowed for the difficulties Mr. Legros was under in giving such an extraordinarily comprehensive survey of the work of very many engineers all working more or less in rivalry. The Paper was to a great extent a model of what a Paper ought to be in describing rival schemes and arrangements, without hurting anybody's feelings. For his part he regarded the Paper as a standard work of reference, and he thought the Author had given a most valuable record of his experience without committing himself too far to opinions on a subject which was still very much open to discussion. He had said little or nothing about steam-tractors as applied to the various purposes, but there was no doubt the steam-tractor would still be heard of a good deal. Mr. Clarkson's coke-fired steamers were very likely to find many applications before long.

Mr. Legros mentioned one of the difficulties that perhaps was the chief difficulty of tractors on land, when he spoke of the nut-cracker action which took place in the chain-track mechanism when clay got into the interstices, and of course sooner or later brought stones with it. Unfortunately under those circumstances it was generally the nut-cracker that was cracked. He had seen a good many tractors lately and he thought that most of them were not sufficiently guarded against picking up stones and dirt. Even where stones did not get in, the wear and tear on the gear was enormous, and the pinions wore out very rapidly, eventually breaking from weakness if not replaced.

The question that interested him most at the present time, as it did so many people, was the agricultural tractor to which Mr. Amos's Paper was an important contribution. He had no doubt at all that the use of the agricultural tractor was going to be one of the chief features in defeating the U-boat, and he believed

(Mr. George Watson.)

it would be an even more important factor if administration kept pace with the efficiency of engineering. The question of speed in cultivation had been dealt with by Mr. Amos in connexion with the farmers' problems, and he thought that was of enormous importance in this climate. If a farmer had a machine which could do his ploughing very rapidly, he was able to take advantage of the few fine days obtained in this country and get the work done at the proper time of the year, when the weather was right. There was no doubt that ploughing in bad and rainy weather was worse than useless, and the motor-tractor gave every farmer an opportunity of doing the work in favourable times.

He did not quite follow Mr. Amos when he said there were certain states of heavy clay land when it was too hard for the motor-tractor to tackle. He had never experienced that, and he thought that, given a reasonable chance, a motor-tractor would tackle any hard land. He had seen a tractor ploughing 7 inches deep on clay which was baked very hard and which had been undisturbed for two years and was full of clover roots; it was ploughing it at the rate of over half an acre an hour, at an expenditure of about $3\frac{1}{2}$ gallons of paraffin per acre. It was working with two furrows, and he had no doubt at all that if that ground had been still harder, had it been possible, the work could have been done, though more slowly, with one furrow.

Mr. Amos had said that the question of speed of the plough did not affect very much the expenditure of power required to plough a given area. He did not quite agree with that. There was a certain speed of plough which was the most advantageous. Mr. Amos spoke of the horse-drawn plough going about 2 miles an hour and the motor plough $3\frac{1}{2}$ miles or faster, but he believed eventually it would be found that motor-ploughs would be driven at about $2\frac{1}{2}$ miles per hour, and that rate would be found to be quite fast enough. The problem was not purely one of friction but of the separation of the earth, and if it was attempted to be done too quickly it was bound to take more power, and therefore to use the power of the engine less efficiently. There was another point about very rapid ploughing: it broke up the furrow and left the

work in an untidy state with green stuff showing. When ploughing more slowly, a longer breast of plough could be used and the furrow turned clean over, and work could be done resembling that which was done in a ploughing match. The question of weight on the land was of enormous importance. The mistake had been made in many cases of sending a motor which was thoroughly suitable for hard land on to soft boggy land or sandy land. Such motors dug themselves in and were not able to tackle the work. In such circumstances there was nothing better than a chain-track tractor to deal with the question.

Mr. Amos had not dealt with one point which seemed of immense importance in the design of agricultural motors, and that was the question of the position on the land on which the motor worked. If it were working entirely on unploughed land, both the wheels being on the level, the tractor could be provided with ordinary axles without any means of adjusting the level, but the drawback to this was that the pull of the draw-bar was always diagonal, and if the land were soft it tended to drag the tractor into the furrow continually, and also tended to drag the plough out of the straight line. He had seen much better work done with tractors that had two wheels in the furrow. They guided themselves so well that he had seen the man in charge get off the tractor and walk beside it, smoking his cigarette, while the tractor went on and did its work. The drawback to having two wheels in a furrow was that it was only possible to have the driving wheels of a certain width, but, given ordinary hard land, he did not think that that presented any real difficulty.

One other point Mr. Amos did not mention which he believed would come to the front with motor traction, and that was the question of subsoiling. A great deal of land would be immensely benefited by having the subsoil disturbed and broken up below the surface of the plough, but it was most important that it should not be brought to the top. Deep ploughing did not meet the case at all. He believed that subsoiling with a cultivator tyne of some sort underneath the ploughshare would become a matter of great importance, and, given sufficient power in the motor to draw the machine, the results would be of very great benefit.

Mr. William H. Patchell (Member of Council) said that on the previous Friday Mr. Legros had read his Paper in Lincoln, where it was highly appreciated by a Meeting of about 200. There was no time for discussion, but after the Meeting there was an informal discussion of which no report would appear, so he would like to mention one point that was brought forward by a speaker who had been in East Africa. Mr. Legros showed two slides, Figs. 15 and 16, Plate 3, of the F.W.D. motor-truck, one carrying ore over sand and the other crossing a wide expanse of alkali-mud, where there was a very heavy road. The gentleman from East Africa said he had been very severely taxed by the difference in track of some of the American motors, and thought it was highly important that there should be some sort of standardization of the track, as Mr. Burford had mentioned.

Following Mr. Watson, one was glad to feel a breath of the country in listening to an old mechanical-implement maker speaking; it took one back again to the olden days. Mr. Watson had mentioned the ploughing by tractors of half an acre an hour. In Hereford the week before last, the Ross tractor ploughing unit held the record with an average per tractor per week of just upon 30 acres. When it was remembered that an acre was what one man could plough in a day, tractor-ploughing showed a great advance. In south Lincoln and in north Cambridge he had known cases where the tractor put across the land was not suitable; its tracks could be seen quite plainly in the following year's crops, and that was not acceptable to a farmer.

Colonel Crompton had mentioned the old Thomson machine. At the time he (Mr. Patchell) was an apprentice he helped to make some and to repair others, and it was not long ago that he had turned up a piece of the old rubber tyres out of a scrap-box. If he remembered rightly, those rubber tyres were 10 or 11 inches wide and $2\frac{1}{2}$ inches thick.

Colonel Crompton said they went up to 15 inches wide and 5 inches thick.

Mr. Patchell said the fascination of that road steamer was so great that an enterprising showman called one day at the works to see if he could have one made in the form of a dragon, capable of wagging its tail, with the exhaust coming out of its mouth! For the reason that Colonel Crompton had mentioned, that idea had to be abandoned!

Major E. G. Beaumont, A.S.C. (M.T.), said there was only one feature in Mr. Legros' Paper he wished to refer to, and that was connected with the irreversible type of differential gear illustrated on pages 62 and 63 of the Paper, and to which particular reference was made on page 71. Mr. Legros stated there that, by the use of that form of differential gear, the third differential on the main shaft could be dispensed with. He rather gathered from the statement in that paragraph that it was not because the machines referred to were four-wheel driven machines and four-wheel steering machines, but because the worm type of differential gear did in fact enable a third differential to be dispensed with. It was easy to understand, with the worm type of differential gear that, although one wheel of the pair on an axle might be actually off the road or slipping, the full torque might be delivered to the wheel which was on the road; but he could foresee that the two wheels on one axle might together have a higher velocity than the pair of the wheels on the other axle, and that therefore between those two axles there still required to be a differential gear if differences of average velocities were to be provided for, as, for example, when a four-wheel driven, two-wheel steering, machine traversed a curve or when there was difference of diameter of the wheels, as sometimes occurred when one set of tyres was partially worn and the other set of tyres was new and of full diameter. The cases quoted of the Jeffery and the Walter quads which employed two differentials were interesting, because for a given radius of turning on a curved path the angularity of the differential joints giving motion to the wheel-driving shafts was very much less than it would be otherwise. That was to say, the use of the four-wheel steering arrangement did reduce the severity of the work on the universal joints, and

(Major E. G. Beaumont, A.S.C.)

moreover also assisted in dispensing with the third differential gear by limiting the difference of average velocity of the two axles. His experience in the working of those four-wheel vehicles was limited, but he had seen the Jeffery and the F. W. D. in service, and he was aware that with those which had only two differentials, wear and tear of universal joints and other parts which felt the stresses in transmission were rapid as compared with others which used the three sets of differential gears. He would be obliged to Mr. Legros if he would explain further the statement with regard to the sufficiency of two as compared with three differentials.

Professor P. M. Baker said there were three questions he would like to bring forward on Mr. Legros' Paper. Referring to the electric drive—mentioned only incidentally by the Author, he said that it was possible to arrange for the electric drive to overcome the difficulty met by irreversible differentials, and it seemed to him that the electric drive would offer great advantages. The fact that it could be made practically to take the place of all the differentials and all the universal joints, and do away with the very awkward driving conditions, would seem to give it a very strong claim in the case of the four-wheel driven vehicle. It was quite possible to arrange for an electric drive—either by means of motors with a considerable shunt field, or by a suitable arrangement of series fields, so that all the effects of the irreversible differential could be obtained. It would even be possible to secure that the maximum torque was exerted on the side which was getting the greatest grip, and this without any attention from the driver.

On looking at some of the vehicles of the chain-track type in Lincoln, it seemed to him that the steering wheel out in front, with a sector and screw to adjust the pressure on the ground surface, was adding another little worry to the steersman, and that probably by some mechanical arrangement, which would avoid the necessity of having to worry the driver with a further appliance to look after in steering, it would be possible to obtain a distinct advantage.

Perhaps Mr. Legros would be good enough to explain how far the method of steering by means of the chain-track was successful, and whether, therefore, the steering-wheel arrangement would not ultimately disappear.

One point which his agricultural friends had been rather insistent upon was, that they said it was all very well for an engineer to speak about the pressure in lb. per sq. inch on the track, in the case of a chain-track tractor, being only so much—less, in fact, than the pressure on the sole of one's foot; but what about the total load distributed over the area—did it not flatten down ridges? It would be rather interesting to know what effects were thus produced in ploughing. Did the tractor ever get across the furrows, and, in doing so, did the ridge get flattened down in an undesirable way by the chain-track tractor? That was hardly a point that Mr. Legros had dealt with, but he thought Mr. Amos might be able to give some information on the subject.

Mr. L. A. Legros, in reply, thanked the Members very much for the extremely kind way in which they had received the Paper. With regard to the remarks of Mr. Burford on the principles underlying the design of commercial vehicles, he was entirely in agreement with him when he spoke of the advisability of adopting the unit principle, but it was necessary that any unit principle of construction should be accompanied by easily operated and easily accessible means of connecting the different units together. The engine must be easily removable from the frame without dismantling much of the transmission gear; the gear-box must be able to be taken out by itself without stripping the chassis of the axles or of the engine, and the same must apply to both the front axle and the rear axle. The axles considered as units should be accompanied by certain parts of the brake-gear, but each axle should be removable independently as a unit.

Figs. 10 and 14, Plates 1 and 2, illustrated units of the type that could be taken down, and the brakes were of the type Mr. Burford had mentioned.

The subject of the final transmission was alluded to in a number

(Mr. L. A. Legros.)

of Papers read before the Institution of Automobile Engineers * relating to questions of gear-box and axle. One of the American four-wheel drive cars was fitted with the internal rack, as shown in Fig. 22 (page 70). Front-wheel brakes were not in his opinion very necessary or valuable except so far as they made the front and back wheels similar in arrangement. It was very desirable that they should be capable of being operated independently.

With regard to the means of steering chain-track tractors, those tractors of lower power which were without front wheels were quite easily controlled by clutches and brakes, and it was usual to lift the front wheel of the Clayton tractor for making sharp turns.

The value of the Paper would certainly have been increased if the reasons which caused the obsolescence of vehicles could have been given. Figs. 40 and 52 (pages 80 and 91), illustrated examples of things that had come and gone, but it would obviously be very unwise to criticize any design that might be going through the period of failure at the present time.

The crossing of land for agricultural work had been alluded to by Colonel Crompton, who had also referred to the road steamers of 1879. The wear which took place between the rubber and the track-chain was, of course, very great in those early cases, more particularly because the conditions suitable to the flow of rubber were then not well understood. Nevertheless, the low figure of 1·5*d.* per mile given in Colonel Crompton's original Paper compared quite favourably with present day expenditure on the tyres of public service vehicles. The evolution of the girdle for haulage vehicles from the Boydell form shown in Fig. 38 (page 79), was an example of the resuscitation, under better conditions, of an idea which had been abandoned for a time.

Mr. Watson had raised the question of the use of steam for chain-track tractors. This was done actually in the Log-Hauler,

---

* Proceedings, Inst. of Automobile Engineers: "Transmission of Power," by L. A. Legros, vol. iii, page 335; "Live Axles for Commercial Vehicles," by Geo. W. Watson, vol. x, page 161; "From Engine to Axle," by Major B. W. Shilson, vol. x, page 333; also, Proceedings, I.Mech.E., "Variable-speed Gears for Motor Road-vehicles," by R. E. Phillips, 1915, page 753.

Figs. 59 to 67, Plates 9 to 11, and in the Model 60 Parsons Ditcher. There was no reason why the chain-track tractor should not be run by steam if so desired, but it should be remembered that the steam-tractor required some extra labour for firing and also time for lighting up, and that it required a much larger supply of water than the total fuel and water capacity provided for the internal-combustion engine.

The picking up of stones and dirt by the chain-tracks was a difficulty with which all the makers were contending, by designing the chain-links or feet so that the joints were better covered and protected.

A great point in designing chain-tracks was the realization of the fact that they were actually geared to the ground surface; increase in the depth of immersion when running on soft ground increased the area of ground to be sheared, and provided more resistance within certain limits. Fig. 95 (page 111) showed how far the track must be pressed into soft ground to get full immersion of the chain; this might vary from a depth of 2 inches to 3 inches according to the make of chain-track used. The figures for the area of tracks given in Table 2 (page 149) were all calculated on the projected area of the chain over so much of its length as would be covered by the depth of full immersion; that is to say, the chain-track was supposed to be run on ground so soft that it would just depress the soil to the depth of the chain as shown in side elevation, and that the level taken would run out on the sloping portions of the ends. The Author was glad of the opportunity of making this statement which defined the data for the insistent weights as given on page 149 of Table 2.

With regard to the question of speed, the American speed for ploughing was generally given as 2½ miles per hour. The Author could not give the full conditions from personal experience, but he could quote that with a machine of 45 h.p., such as shown in some of the illustrations, the amount ploughed was about 20 acres per day. This speed was nearly treble the record obtained in recent returns for the southern English counties now being ploughed by wheeled tractors. The increased rate was obtained by increasing

(Mr. L. A. Legros.)

the number of plough-shares rather than by increasing the actual speed of ploughing.

Major Beaumont was perfectly correct in saying that the necessity for the third differential was not entirely eliminated by either the M. & S. or the Walter differential; although the worm differentials did not absolutely dispense with the necessity of a differential between the front and back axles, they performed their intended function in turning curves. It was perfectly true that extra work was required of the differentials on axles which comprised steering joints, because the articulations or Hooke's joints on each end of the axle were not kept in phase as was the case with the similar joints on the Cardan shaft or propeller-shaft of the ordinary car.

The electric drive was, of course, quite easy to control by means of a very simple controller, and, as would be seen in Fig. 32, Plate 6, the amount of complication introduced by separate electric motors in each wheel was that there were in all eight bevel-pinions and eight bevel-wheels with the independent electric drive, whereas with the mechanical arrangement of three differentials there were four bevel-wheels as well as the whole of the gear of three differentials amounting to twelve more bevel or mitre wheels.

Communications.

Mr. ARNOLD A. ARNOLD wrote that the references in the Paper to the insistent load for chain-track tractors, also the means of steering when this was by the tracks alone, pointed to the necessity of providing such vehicles, when intended for use on soft ground from which a man would be unable to extricate himself if he stepped off the machine, with at least three large chain-tracks in case of one becoming broken in service; otherwise, on account of repairs to the broken track being extremely difficult, if not impossible, due to the nature of the ground on which they would require to be effected, the tractor could not even be hauled out readily, because it would probably be unstable, and the insistent load would be very greatly increased. The case would also be further aggravated as

the tractor would have no means of proceeding by its own efforts, because the means of propulsion were then impaired and the means of steering entirely absent; it could then only take a more or less circular path or would turn round continuously. That is to say, the breakage of a single chain-track at once robbed the class of tractor referred to of means both for driving and for steering, which was a very serious matter under the circumstances stated, and placed this type of tractor at a very great disadvantage as compared with those having means of driving independent of those for steering; a tractor of the latter type with one chain-track broken might possibly proceed, although somewhat erratically in its course, over open country.

With three chain-tracks, should the central one fail, the insistent load would be somewhat increased, and the steering would not be materially affected. Should an outer chain-track fail, the tractor with a wide central chain-track to give a suitably low insistent load, might proceed, if not unstable, with the two remaining chain-tracks by means of which steering could be effected although somewhat imperfectly. Facilities for separate operation of the three chain-tracks would be essential, and the construction might therefore be complicated, but might be warranted by circumstances.

It was not quite apparent why the weight of engines was of little importance, and why the engines should run at comparatively low piston-speeds, thereby increasing the weight for a given engine power. Unnecessary weight in the engines increased the loads on the chain-tracks and placed the centre of gravity of the tractor higher than would otherwise be the case, both of which effects would appear to be disadvantageous, especially for service on bad roads. As a large speed-reduction would probably be necessary, the provision of gearing for that purpose should not be insurmountable, except perhaps on the score of expense.

Mr. Victor F. Feeny wrote that the chain-track vehicle was at present, he believed, an illegal vehicle for use on roads, in that it did not comply with the Act regulating motor traffic on highways. It was to be hoped, in view of the immense future before this type

(Mr. Victor F. Feeny.)

of vehicle, that the Local Government Board would see that the necessary legislation was passed. A similar law was still in force in California, U.S.A., but some years ago it was decided by the State Government that chain-track vehicles would be allowed on all State Highways without fitting any cushioning attachment to the track shoes. The California State Highways were about the finest in the United States, and the top dressing there was soft asphalt. It was remarkable how little the good roads were marked or damaged by chain-tracks when grousers or spuds were not fitted.

The best published acreage per wheeled tractor belonging to the Food Production Department in the United Kingdom was about 35 acres per week. The fuel consumption was also about 5 gallons per acre. With an efficient chain-track tractor of equal horse-power, there would be no difficulty in averaging sixty or more acres per week, because difficulties which prevented a wheel-tractor operating on soft land were avoided in the case of a chain-track tractor. The fuel consumption per acre would also automatically decrease, because of the difference between the insistent loads of the wheel and chain-track tractors.

A tremendous impetus had been given to the chain-track movement in the United States, and the figures relating to the chain-track tractors (all of one make) ordered by the American Government were surprising. For hauling guns the wheel-tractor had been entirely eliminated. It was much to be regretted, in view of the desire to put so many more millions of acres under cultivation in the United Kingdom, that more chain-track vehicles could not be obtained, but military requirements seemed to have taken precedence entirely.

Mr. Henry McLaren wrote that Mr. Legros, when in Leeds, gave them a very interesting Lecture. As Chairman of the Leeds Meeting, he not only thanked Mr. Legros and Mr. Amos, but also the Council of the Institution for having this Paper read in Leeds, where many members and others were employed in making this class of machinery. He proposed to confine his remarks to the ploughing section of the Paper contributed by Mr. Amos.

Before serving his apprenticeship to engineering, he (Mr. McLaren) was intimately connected with farming and the practical working of steam-ploughs on the farm. Forty-two years ago, in conjunction with his brother, they established their present business for the manufacture of traction-engines and steam-ploughing tackle, and to-day their output was about equally divided between these two branches. Therefore both sections of the Paper interested him. His remarks might be unfavourable to the motor-tractors for use in this country as a commercial proposition, yet he was quite in accord with the Government policy of using them as much as possible during the war, especially at the moderate charge to the farmer of 15*s.* per acre, even if the actual cost were three or four times that amount.

Mr. Amos stated quite rightly, that ploughing done *immediately* after harvest was best, and gave good and sufficient reasons for his contention; but when he stated that the chief value of the motor to the farmer was that it enabled him to get this done, he (Mr. McLaren) replied that the farmer did not get it done quickly enough. Recently Mr. George Lambert, in the House of Commons, asked for a return showing the number of Government tractors in use and the acreage ploughed. Mr. Prothero, in his reply, gave a Table of Results, Table 3 (page 172), and also stated that the weather had been exceptionally bad. He had therefore added a fourth column to the Table, showing the percentage of time lost through bad weather, and he (Mr. McLaren) had added a fifth column, showing the acres that would have been ploughed had there been no time lost by bad weather. It would be seen that, during the six weeks ending 12th January, the average acreage ploughed per week per tractor was only 4·39 acres per week, or 0·73 acre per day. The fifth column showed that had there been no lost time through weather, the average would have been 6·56 acres per week per tractor. Therefore the work done by each tractor was just about equal to that expected from a single-furrow plough, worked by a ploughman and a good pair of horses. These results were altogether too meagre.

Tractors depended upon light lands for getting up their averages,

(Mr. Henry McLaren.)

yet he had heard of a case in the North of England, where a Government tractor, and a man with three horses and a double-furrow plough, started work at the same time on easy going land. When the tractor had finished, the lands were measured, and the result was in favour of the horses in the proportion of 8 to 5. There was no breakdown of the tractor, but just the usual frequent stops for adjustment, which proved so irritating to the users of these machines.

TABLE 3.

Week ending.	Number of Tractors in commission in hands of County Committees.	Number of Acres ploughed.	Average Number of Acres ploughed per Tractor.	Working hours idle on account of weather.	Working full time.
				Percent.	
8th December 1917 .	1,708	12,609	7·38	11·13	8·3
15th ,, ,, . .	1,721	12,417	7·22	13·36	8·33
22nd ,, ,, . .	1,718	5,020	2·92	52·71	6·17
29th ,, ,, . .	1,733	2,090	1·21	67·33	3·7
5th January 1918 . .	1,760	8,303	4·72	30·72	6·8
12th ,, ,, . .	1,813	5,187	2·86	52·85	6·06
Average for 6 weeks . .	—	—	4·39	38·0	6·56

Owing to the shortness of food, everyone was interested in the progress of the ploughing tractors. A few days ago it was stated in a Leeds newspaper that 27 acres had been ploughed in one week by a single motor-tractor, and that a week's favourable weather had enabled 200 tractors in Yorkshire to plough 1,300 acres. This was an average of 6·5 acres per week per tractor, which confirmed the figures in the fifth column of Table 3 for favourable weather conditions. It also mentioned that the majority of the Yorkshire tractors weighed 2 tons and pulled three-furrow ploughs, but that

lighter tractors, pulling two-furrows, might be preferable for Yorkshire. This opinion might be in anticipation of the six thousand two-furrow Ford tractors which were now due.

He agreed with the remarks of Mr. Amos on the effect of heavy engines passing over certain lands in unfavourable weather. He remembered a field of grain, ripe for harvesting, showing two green trails where the previous year a ploughing engine had passed over the ploughed land to get out of the field. Not only were the wheel marks green, but the heads of grain were stunted, and of poor quality. Yet he had known the same engines pass over that same field many times without leaving any trace of damage on the following crops. It all depended on the condition of the land, and that in turn depended on the weather. He was now referring to clay lands; there were other lands where not a trace of damage could be found under any circumstances.

He would now deal with the question of heavy versus light tractors for use in Britain. If the British farmer only used his tractor for ploughing immediately after harvest, pulling as many ploughs as possible for so long as the good weather lasted, he would do *more* and *better* work with heavy tractors than was possible with the light machines working all through the winter months. For winter ploughing in this country the light tractor was a necessity, and the lighter the better.

His (Mr. McLaren's) firm only made steam-tractors. The lightest weighed 5 tons, which they did not recommend except in special cases. There was a wide zone on the earth's surface peculiarly adapted for tractor ploughing, where troubles incidental to the British climate were eliminated, and they confined their efforts to this zone. His firm had been competitors at most of the important European Tractor Ploughing Competitions, including the Royal Agricultural Society's Trials in England, and had been uniformly successful in gaining the First Prize. This was partly due to the fact that these competitions were usually held immediately after harvest, before the land had become sodden by rain. They generally used an 8-ton tractor in these European Competitions, and ploughed from $1\frac{1}{2}$ to $2\frac{1}{2}$ acres per hour.

(Mr. Henry McLaren.)

Mr. Amos mentioned the question of narrow headlands. His own practice was to leave a margin at each side of the field, of equal width to the required headlands, and then to plough all round. It made no difference to the crop whether the land was ploughed north, east, south or west, but it made a considerable difference to the amount of land ploughed, when it was possible to plough all the time, instead of running empty along the headlands.

Mr. Amos stated there was no motor-drawn plough that could deal with hard baked sun-dried clay land. His own firm was dealing with this class of land regularly. About eight years ago in India they ploughed 521 acres in forty days—an average of 13 acres per day—8 inches deep, at a cost of 4*s.* 9*d.* per acre, and made a first class job, with a tractor weighing 13 tons pulling extra strong ploughs specially made for the job. The land was absolutely dry and terribly hard, and the ploughs chattered exactly like a road scarifier, so they had to rivet up every bolt in the ploughs to keep the nuts in place, and fit the share-bolts with spring washers, and even these needed constant attention. Since then he had seen land in Central Africa, equally as hard as the Indian land, but without a semblance of a crack on its surface. Up till recently this land could only be ploughed when moist; then immediately it was ploughed the vegetation again sprang up, so that before seed time it had to be ploughed again. They were now able to let that land get thoroughly dry, and then to plough it with special direct traction ploughs. There was not a green blade growing on it until the rains came.

He considered the double-engine cable system to be the only suitable method of mechanical ploughing in this erratic climate. The cable system was the survival of the fittest. It had carried on through all the bad times of agriculture, contractors ploughing for as little as 7*s.* per acre. The engines and tackle were well made, of the best materials, and appeared to be everlasting. There were numbers of these sets working in England to-day, which were over forty years old, whereas the life of a tractor was about four years. Double-engine tackles were now being used by Government, and were useful for contract work.

Mr. Robert E. Phillips wrote that he would like to call attention to the fact that Mr. Amos was not alone in advocating the use of a balanced or duplex one-way plough driven by a self-contained motor unit, for as far back as 1895 a patent was granted to one L. B. Bethell, of Kingswood Warren, Epsom, for a balanced one-way plough having an internal-combustion engine power unit centrally arranged. He agreed with Mr. Amos that with a machine of this type the width of the headlands and the time occupied in turning could both be reduced to a minimum. The drawback, however, to this type of machine was that it could not be adapted for any other use, that is to say, so readily adapted that its conversion would be a paying proposition.

With an ordinary tractor multiple-plough, the width of the headland to be subsequently ploughed could be materially reduced by employing a form of lifting tackle which, when lifting the multiple-plough would raise the front plough in advance of the rear plough or ploughs, and when lowering the same, would lower the front plough in advance of the rear plough or ploughs. This enabled the furrows turned by all the ploughs to be continued right up to the same line at the headlands, and in effect reduced the width of the headland to be subsequently ploughed to the overall length of the plough itself.

The most practical solution of the one-way plough which would work with a minimum width of headland, that had come within the writer's notice, was one in which the two ploughs were arranged side by side, and were so mounted that they could be swung transversely in relation to the frame of the tractor to bring them into and out of their operative positions after having been raised clear of the ground by the lifting mechanism before referred to. This arrangement enabled a very compact machine to be produced. The overall length was reduced by at least the length of one plough, and the overall width was not increased. The experimental machines which had been built on these lines gave most hopeful results.

Mr. Amos had made no reference to one great defect in the ordinary tractor-plough which the one-way plough overcame, that was the tendency for the plough to slip away from its work when

(Mr. Robert E. Phillips.)

ploughing across a slope and the furrow slices were being turned in the direction of the up gradient of the slope unless it was directly controlled by an operator following the plough, which called for the employment of an additional man who must, moreover, be more or less skilled.

Mr. Amos referred to the tendency of tractors to slide down hill when travelling across a slope, and the damage done thereby. This was without doubt a difficulty that had to be overcome, and the writer thought that this end would be attained by employing a steering of the centrally articulated type which lent itself particularly well to agricultural tractors, as the motor unit could be carried by the front part of the frame and the tilling implement by the rear part thereof. If, in conjunction with such a method of steering, a single rear-wheel capable of turning on a vertical axis were also employed, the tractor could be turned in a minimum space relative to the overall length of the machine.

He thought the Institution was greatly indebted to Mr. Legros for his very comprehensive Paper on a subject which was much to the fore at the present time. The Paper was one which did not call for criticism, and the only remarks he offered were entirely from the historical point of view. In the first place he (Mr. Phillips) invented in about 1882 the double-driving gear referred to as the "Hedgeland." This mechanism was nothing more than a double driving two-way clutch, and was designed for transmitting power equally to the two driving wheels of a tricycle without using the "Starley" balance gear.

In the next place, the credit for the "positive drive" or limited action—as he preferred to call it—differential gear was due to Gavin C. Goodhart and the "M. & S.", the "Walter" and the "Wolseley" gears described by the Author were based on the principle enunciated by Goodhart, namely, the introduction into the gearing of a pre-determined amount of internal friction in proportion to the driving torque. In Mr. Goodhart's experimental gears, some of which were made as far back as 1912, the internal friction was produced either by increasing the friction created by the end-thrust of the wheels of the gear or by increasing the

friction between the teeth of wheels. From recent trials of heavy motor tractors with solid axles, that is, axles in which both driving wheels were fixed solid with the axle—no differential being used—it would seem that even for road work the differential gear could be dispensed with, without detriment either to the tyres or to the vehicle generally. If this were so, it would seem to point to the fact that the differential gear could be dispensed with on agricultural tractors and other vehicles intended to travel principally on the land.

Mr. Robert Royds wrote that, in his opinion, the title of Mr. Legros' Paper seemed somewhat more comprehensive than the treatment of the subject warranted, and, judging from the illustrations in the Paper, there appeared to be too much bias in favour of the internal-combustion engine. Whilst it was probably true that the oil-engine was well adapted for American conditions of oil supply, the general problem could not be separated from the motive-power engine, and it was somewhat doubtful whether the oil-engine was to be preferred to the steam-engine tractor for places such as the British Isles, India, South Africa, Australia, South America, etc. To make the Paper more in keeping with its title, the writer would suggest that it would be a decided advantage to manufacturers of tractors in this country if Mr. Legros could see his way to summarize the relative position of steam-tractors and oil-engine tractors as regards adaptability, first cost, cost of upkeep, cost of fuel, etc.

Mr. Wilfrid L. Spence wrote that he could recall no recent Paper on automobile engineering matters which had interested him quite so much as this one on what might almost still freely be described as "Freak Tractors." The Author's presentation was timely, and his very full treatment was no more than commensurate with the importance of a subject whose rapid development and the diversity of applications of which came as a revelation. The writer's study of Mr. Legros' Paper, together with his own observations, and a careful perusal of land tractor reports and correspondence had led him, for his own guidance, to formulate the following propositions and deductions :—

(Mr. Wilfrid L. Spence.)

It was quite wrong to affirm (as had constantly been the case) that when a two-wheel drive 3-wheel or 4-wheel tractor failed to pull, the ground was necessarily unfit for cultivation. There were in fact in our climate very many days when the land, too soft to carry the weight or too slippery for the grip of such tractors, would be ploughed or cultivated by horses or by a rolling-track tractor. Consequently no land tractor should, other things being equal, weigh one pound more than was absolutely essential to secure adequate tractive adhesion for its maximum duty. Steering wheels and steering rolling-tracks not driven, and of course, mere load-carrying wheels, contributed nothing to adhesion, they were evidence of defective design and should be eliminated. Arising from the foregoing, the entire weight of a completely successful land tractor must be carried on the driving wheels or rolling-track. It was not an effective argument against this to say that all the tractor weight was, under heavy tractive effort, transferred to the driving wheels, for in that case not only would steering be impossible, but the intensity of loading on the driving wheels would be destructive to the land.

There remained therefore three broad types only which could be fully successful under bad conditions, namely :—

(1) The two-wheel tractor, both wheels driven, for light work.
(2) The four-wheel drive tractor.
(3) The pure chain or rolling-track tractor (without steering wheels or steering rolling-track).

The chain-track, other things being equal, added nothing to adhesion—its purpose was to prevent sinking in excessively soft ground by means of increased contact area and reduction of load intensity, hence it was not superior in effective tractive effort to a four-wheel drive tractor. If the four-wheel drive tractor could be built with wheels large enough to obviate sinking in soft ground, it was obviously superior to the rolling-track machine in respect of simplicity, first cost, maintenance, and transmission efficiency. There should be no insuperable or even great difficulty in designing a four-wheel drive tractor to meet the conditions named. Such a

machine would do everything that a chain-track machine could do except, perhaps, climbing steps of certain pitches which may demand actual "caterpillar" or "tank" action, the gradual fore-to-aft transference of the ground contact. Such a condition might be exemplified by a small hog-back bridge of high rise leaving both fore and aft wheels in the air. For ultimate simplicity, low capital cost, low maintenance and high economy, this four-wheel drive tractor should have no differential gears, no exposed gears of any kind whatsoever, no universal joints and no steering gear. It would be steered by power like the pure chain-track machine, by clutch action or the equivalent.

For positively marshy ground where a loading of the order of 5 lb. per square inch or less was necessary, it was thought that a flexible band rolling track could be added over the driving-wheels. This band would be straked for grip and supported by closely set rollers as for a chain track. Built as a double-ended machine, running indifferently in both directions and carrying reversed ploughs at each end, as with steam-ploughing tackle, this equipment would save all the time wasted at headlands, and with three 12 inch ploughs in a sufficiently large field might easily plough 10 acres per day of ten hours.

Mr. L. A. Legros wrote that he had been glad to learn from Sir W. A. Tritton that the description of the "Centipede" quoted in the footnote on page 94 was inaccurate, and the explanation was that his firm, Wm. Foster and Co., Ltd., were at the time building two types of machines, and the description referred to had become mixed and contained details of both, hence the apparent inefficiency alluded to by the Author.

Mr. A. A. Arnold had mentioned (page 168) the need for three chain-tracks for vehicles intended for use on very soft ground. This question had been considered for other than agricultural conditions, but for quite a different reason, which did not arise in agriculture. If the ground were so soft that a man could not walk over it, and therefore that the vehicle could not be drawn out, those conditions that might cause fracture of the chain-track were

(Mr. L. A. Legros.)

not likely to be found. The case might be taken as parallel to the driving over ordinary roads of a four-wheeled vehicle which would be disabled by fracture of either an axle or a wheel; nevertheless the six-wheeled road vehicle had found but few advocates in the past and had not any vogue at present.

The reason why the weight of the motor was of little importance was to be found in the fact that the weight of four-cylinder commercial-vehicle engines, with cast-iron crank-cases, was about 22 lb. per h.p., whereas the weight of four-cylinder passenger-car engines was about 11 lb. per h.p. The saving in weight for the engine of a 50 h.p. chain-track tractor would accordingly be some 5 cwt., and as this would only amount to about 4 per cent. of the weight of the vehicle, it would be consequently hardly worth considering. The use of slow-speed engines running at about one-half the piston speed of the passenger-car engine contributed to longer life of the power-unit, and did not demand so large a reduction ratio in the gear, but as the strength and dimensions of the gear teeth were decided by the speed of the vehicle and the power to be transmitted, the ratio of reduction had very little bearing on the weight of the vehicle.

Mr. V. F. Feeny had raised a very important point with regard to the use of chain-tracks on ordinary roads (page 169). It had been pointed out by Colonel Crompton that much damage had been done to roads by hauling heavy loads on vehicles fitted with small wheels, and therefore having a very high insistent weight. A bad case cited by him was that of the ordinary boiler lorry, and he had stated that a scrapped Lancashire boiler hauled on a wheeled lorry by a wheeled tractor from its place to the scrap merchant's yard might easily cause damage to the road exceeding the value of the scrap itself, let alone the value of the scrap less the cost of haulage. This was a very serious consideration, and one that was worthy of the attention both of the Road Board and of the Local Government Board, for the good of the community.

It was highly desirable that the chain-track system should be recognized by those bodies, and that reasonable regulations should be framed for width, form of track, and permissible speeds under the different conditions of running light, as in a haulage wagon,

and of hauling a load, as in a tractor, as well as for the maximum insistent loads permissible on chain-track haulage wagons and chain-track tractors.

Since Mr. Feeny's communication was written it had been claimed * that the record for a week's ploughing with a Government tractor had been made by a "Titan" wheeled tractor hauling a Ransome three-furrow plough, and that 51 acres had been ploughed in 66·5 hours at Redhill (Surrey); the previous record was stated to be 48 acres under long grass, and the fuel consumption was given as 4 gallons of paraffin per acre. Unfortunately in neither case was the depth given, and this was a most important factor in comparing area ploughed, fuel consumption, and cost.

After delivering his Lecture at Glasgow, the Author had been informed that, for producing a satisfactory potato crop from the fields of the Scottish lowlands, a depth of ploughing of 10·5 inches was necessary. Now it was probable that the power required for ploughing varied as the area of the ground section turned over, that is as the product of depth by width, or if these were in the same ratio it varied as the square of the depth. Hence it would follow that the expenditure of power per acre would vary as the depth, and to plough 10·5 inches deep would require an expenditure of 75 per cent. more fuel than for furrows 6 inches deep; moreover, the tractor would only be capable of hauling a proportionately reduced number of ploughshares, in this case four instead of the seven it might haul when ploughing only 6 inches deep. The actual draw-bar pull for ploughing 6 inches deep by 9 inches wide had been measured by Mr. Alan E. L. Chorlton, C.B.E. (*Member*), as varying from 500 lb. per share at 2 miles per hour in medium soil to 766 lb. per share at 1·57 miles per hour in stiff clay land.† The speed of ploughing in the United States appeared to be about 2·5 miles per hour, and it was claimed that a No. 18 Yuba tractor (35 h.p.) ploughed 20 acres per day to a depth

---

* *The Engineer*, vol. 125, March 1918, page 207.

† Proceedings, Inst. of Automobile Engineers, "An Agricultural Power Unit," vol. xii (1917–18).

(Mr. L. A. Legros.)

of 6 inches by 14 inches wide at a cost of 40 cents per acre. For 370 acres the fuel consumption was given as 500 gallons of gasoline, 30 gallons of cylinder oil and 35 gallons of heavy oil, which at the recent price of 3*s.* per gallon for petrol and 2*s.* for cylinder oil would be about 5*s.* per acre for fuel in Britain.

In another instance a tractor of the same power was quoted as doing 18 acres per day of 10 hours with an average expenditure of 18 h.p., and using 2 gallons of distillate * per acre.

In Wisconsin a Killen-Strait tractor was stated to have prepared 7 to 8 acres per day hauling two 24-inch breakers, and to haul four 14-inch breakers, when dealing with swamp.

The Holt Caterpillar figures obtained in comparison with horse haulage were as follows:—horse-labour 4·9 to 3 hours per day per horse at a cost of 7·7 to 14·9 cents per hour; or at 1 acre per day for two or three horses respectively, from $0.75 to $1.34 per acre. The Caterpillar tractor ploughed 3,920 acres in 114 days, or 34·3 acres per day, at a cost of 24·5 cents per acre. This amount was composed of:—engineer's wages 12·2 cents, distillate 6·1 cents, plough tender 2·7 cents and lubricating oil, extras, etc., 3·5 cents.

For harrowing by 45 h.p. tractor the amount was given as 125 acres per day. In all these instances it must be remembered that the fields were of very large size, and there was not the same need for reducing the headlands as in Britain.

At the Manchester lecture the President had referred to the importance of cost in considering the work done by chain-track tractors, and the Author quoted that an Austin ditcher was reported to have cut over 9·5 miles of ditch, 4 feet 6 inches deep, shifting 50,000 cubic yards of dirt at a cost of only 3 cents per cubic yard.

At the Leeds lecture Mr. McLaren had given the Government charge for tractor ploughing as 15*s.* per acre, whereas at Glasgow he learnt it was 25*s.* per acre or double the pre-war price of 12*s.* 6*d.* per acre. Seven acres ploughed by one ploughman with two horses for 6 days was apparently considered a fair average in

* *See* footnote, page 97.

Scotland. The subject of ploughing by tractor had aroused much interest in the north, and demonstrations had been made of twenty-nine tractors at Edinburgh, Glasgow and Perth.*

The figures given by Mr. McLaren for cost of ploughing (page 171) required some further comment. The charge of 15*s.* per acre was in force in England and Wales till October 1917, when it was raised to 20*s.* per acre for land of ordinary quality and for furrow depths of 6 inches in grass and 7 inches in stubble or fallow land, 2*s.* 6*d.* extra per acre being charged for each additional inch of depth, with a further extra charge for fields of very small size or irregular shape, or for exceptional conditions. Where shallow ploughing was found advisable in the interest of food production the charge might be reduced to 17*s.* 6*d.* per acre for ploughing light soil to a depth of 5 inches, and for skimming stronger land to a depth of 4 inches.

The charge for cultivating varied in different counties, but was usually one-third of the charge for ploughing the land, or about 6*s.* 6*d.* per acre. For double cultivating cross-ways, the charge in some instances amounted to 20*s.* per acre. A charge of 25 per cent. extra was made when, as in some parts of Surrey, a land press was used with the plough. For disk-harrowing the charge was about 4*s.* per acre. Scotland and Ireland came under other regulations.

In order to permit of comparing these prices at a later date with those of horse traction, it would be of interest to note that the present cost of a horse, cart, and man per week was reckoned as follows:—

	£	*s.*	*d.*
Horse, including insurance, interest, keep, and depreciation on £75	2	19	0
Cart, including interest, repairs, and depreciation on £20 . .		6	2
Man, including insurances and holiday allowance. . . .	2	8	9
Office expenses		4	0
Total	£5	17	11

* *See* Highland and Agricultural Society of Scotland, "Demonstration of Agricultural Tractors," October 1917, William Blackwood and Sons, Edinburgh and London.

(Mr. L. A. Legros.)

Mr. McLaren had alluded (page 174) to the fact that the direction of the ploughing made no difference to the crop. It might be thought a heresy by farmers, but he (Mr. Legros) would suggest that the most efficient way of ploughing would be to go round continually in a spiral and finish the remaining approximately triangular corners afterwards; by this means there would be no stoppage for turning, and more than three-fourths of the field would be completed at a continuous run; furthermore, as the insistent load on the chain-track was so small, the greater part of these corners could be done by lifting the plough over the ploughed portion and making two or three more turns round the field.

Mr. W. D. Collins, of Fulfords, Horsham, had since shown the Author examples of ploughing 14 feet wide with a gang of ploughs fitted with the automatic lifting and lowering gear mentioned by Mr. R. E. Phillips (page 175). These were hauled by a 75 h.p. Caterpillar, and the procedure was to mark off 28 feet at each end of the field for turning, and leave 14 feet at each side. After all the centre had been ploughed the tractor was taken across, ploughing each end, and running down the sides with the ploughs raised, after which it was run all round the field. The corners left untouched amounted to the difference between the area of a ten yard square and a ten yard diameter circle, or about 22 square yards only. Mr. Collins stated that he could exceed 2 acres per hour when at work, using the heaviest ploughs intended for steam-tractor haulage. He had also used the Caterpillar for cultivating to a depth of from 15 inches to 18 inches, hauling a Fowler cultivator weighing $2\frac{1}{2}$ tons with 11 tynes cultivating 9 feet in width.

Mr. Robert E. Phillips had mentioned (page 176) his prior invention of the positive-drive differential; apparently this was one of the many cases that occurred of an invention being produced previous to the existence of the conditions necessary for its adoption on a commercial scale; to a smaller extent it resembled in this respect the invention of the chain-track. Dispensing with the differential altogether as suggested by Mr. Phillips might not be very detrimental to the vehicle, but it might well cause considerable damage to the road by loosening stones at the surface and thus starting the action which produced pot-holes.

In reply to the remarks of Mr. Robert Royds (page 177), the Author had given particulars of two steam-driven machines—the Log-Hauler and the Model 60 Parsons Trench Excavator. These examples sufficed to show that steam-power had been applied to chain-tractors as readily as the petrol or the oil-engine, but it must be remembered that the steam-engine required a supply of fuel, a large quantity of water and constant attention over and above that necessary for running an internal-combustion engine. If an insistent weight of 8 lb. or 9 lb. per square inch on the chain-tracks were admissible, there was no reason why steam chain-track tractors should not be made and work successfully under overseas conditions where petrol and paraffin could not compete with local fuel suitable for steam generating.

At the Glasgow lecture it had been pointed out that the Author had not dealt with the large class of light wheeled agricultural tractors, but had confined himself to the two most recent developments—the four-wheel drive and the chain-track tractor. Several of the problems which arose had been treated by Mr. A. E. L. Chorlton, C.B.E., in his Paper to which reference had already been made.* He gave resistance of a spud as 50 to 75 lb. per square inch for land in which the plough resistance would be 9 lb. per square inch; the rolling resistance of a tractor weighing 3·25 tons with driving wheels 4 feet 6 inches in diameter and 15 inches wide was given as 900 lb. total, or 277 lb. per ton, the wheels being fitted with spuds. He also gave in diagram form the displacement of the wheel loads to which the Author had referred on page 60. The rolling resistance quoted, amounting to practically 12 per cent. of the weight for the wheeled tractor, did not compare very favourably with the rolling resistance of the chain-track; the Ball-Tread tractor was stated to coast down a gradient of 1 in 33 and a 75 h.p. Holt caterpillar, in use in Sussex, was reported as now being fitted with brakes, because it would coast down a gradient 1 in 15.

---

* Proceedings, Inst. of Automobile Engineers, "An Agricultural Power Unit," vol. xii, 1917–18.

(Mr. L. A. Legros.)

As the wheeled tractor had so many advocates, that of twenty-nine tractors demonstrated in Scotland, twenty-four were of wheeled types and only 5 chain-tracks, and as the Ministry of Munitions (M.O.M.) tractor was also of the wheeled type, an Appendix was being added (pages 187 to 191) giving the leading particulars of some of these tractors; unfortunately it was not possible to give illustrations of these wheeled tractors at work, though four of the five chain-track vehicles used in the Scottish demonstrations were illustrated in the Paper.

Mr. W. L. Spence had mentioned the difficulty of ploughing and cultivating on soft and slippery ground (page 178); in designing the track-shoes of a chain-track, it was necessary that the track should gear with the ground (page 92); with too small an insistent load, the projections on the shoes would not get sufficient bite on clay or grass land. Actually the conditions were more favourable for the chain-track, for whereas a wheel only engaged one or two spuds, a chain-track might engage on eight to twenty-four or more gearing surfaces, most of which were kept in contact by the loading wheels of the truck-frame; in this matter he disagreed entirely with Mr. Spence. The difficult condition to deal with was that which occurred when the interspace between the projections became filled with clay, so reducing the area of ground in shear to less than one-half and causing slipping to occur. One of the most vital problems was that of how to obtain sufficient penetration for effective gearing with the ground when working on the land, and how to alter or adapt the chain-track so as to be capable of running over the road without damage. The tendency of design of low-powered chain-track tractors was to dispense with steering wheels and to steer by clutches and brakes on the two chain-tracks themselves as suggested by Mr. Spence.

The Author was of the opinion that while it would be quite possible to construct a four-wheel drive tractor such as Mr. Spence had suggested, and to steer it by clutches instead of by steering gear, experience in turning rigid wheel-base vehicles, even on the hard road, showed that serious digging action took place, and even the steam-roller required a pivoting action for its front wheel. Such a

tractor as Mr. Spence had described would require a large radius at each side of the wheels to avoid this digging action. The flexible band rolling-track would, the Author feared, be a return, under worse conditions, to the belt form of drive long since abandoned for motor vehicles.

Altogether too much case had been made of the complication of the chain-track and of the track frame. The whole tendency of modern machine-design was to obtain commercial efficiency regardless of multiplication of such parts as could be manufactured in quantity. The early bicycle with its direct drive and plain bearings had given way to the safety bicycle with its ball bearings and chain drive, introducing some hundred or more extra parts in order to obtain greater convenience, safety, and efficiency. When the chain-track had been in use for as long as the safety bicycle, and had thirty years of experience behind it, a similar comparison to that of the types of bicycle could probably be made between wheeled and chain-track tractors.

APPENDIX III.—The Bates Steel Mule.

After the Paper was written the Author received particulars of the Bates Steel Mule which differed in many respects from the chain-track tractors described. It has a single central chain-track for driving and two leading wheels carried in vertically pivoted forked bearings for steering. The original feature of the design is that it is arranged to be driven from the seat of any existing appliance—plough, harrow, cultivator, reaper, etc.—originally intended for horse-haulage. The controls are operated by a control column consisting of three co-axial wheels and a lever all arranged on the back ends of three concentric tubes. The control column is carried on a universal joint at the tractor-end which permits it to be swivelled to any required angle. Steering is effected by the middle wheel and tube; the larger wheel in front of this, that is nearer the tractor, is used to operate the clutch; the small wheel at the rear, that is nearest the driver, is used for gear changing. The lever projecting in front of the forward wheel is for the carburettor control. When ploughing, one of the front wheels runs in the furrow, and it is claimed that under these conditions the machine

(Mr. L. A. Legros.)

TABLE 4 (*continued on opposite page*).

Wheeled Tractors.

No.	Tractor.	h.p.	Cylinders.			Rated.	Main Clutch.
			No.	Bore.	Stroke.		
	Four-Wheeled.			in.	in.	r.p.m.	
1	Alldays General Purpose ‖	25	4	3·94	5·12	1,000	cone
2	Clydesdale ‖	25	4	4·25	5·5	900	multi-disk
3	Denning	20	4	4·25	5·75	900	integrating disk
4	,,	16	4	3·5	5·25	1,000	,,
5	Emerson ‖	30	4	4·5	5·0	800	cone
6	G. W. W. ‖	30	4	4·25	5·75	900	expanding
7	Light All-work	30	4	5·0	6·0	600	disk
8	Mann's Light Steam ‖	25	2	4·0*	7·0	450	throttle
9	Marshall	60	4	7·0	7·0	800	cone
10	,,	30	2	7·0	7·0	800	,,
11	Mogul ‖	25	2	7·0	8·0	550	expanding
12	,, ‖	20	1	8·5	12·0	400	,,
13	,, ‖	16	1	8·0	12·0	400	contracting
14	M. O. M. (Fordson)	22	4	4·0	5·0	1,000	multi-disk
15	Morse Light Farm	20	4	3·5	5·25	1,200	integrating disk
16	Overtime ‖	24	2	6·0	7·0	400	cone
17	Plow Boy	20	4	3·5	4·25	950	expanding
18	Plow Man (Interstate)	30	4	5·25	5·5	850	,,
19	Titan ‖	20	2	6·5	8·0	500	,,
20	Weeks-Dungey ‖	26	4	3·75	5·25	900	disk
	Three-Wheeled.						
21	Allis-Chalmers ‖	18	2	5·25	7·0	720	expanding
22	Peoria	20	4	3·75	5·0	1,000	,,
23	Farmer Boy	24	4	3·75	5·25	1,100	multi-disk
24	Ivel-Hart	22	2†	5·5	7·0	600	disk
25	Kingsway ‖	16	2	5·75	7·0	750	contracting
26	Samson Sieve-Grip ‖	25	4	4·25	6·75	650	expanding
27	Wallis Junior ‖	30	4	4·25	5·75	900	,,
28	Whiting-Bull ‖	24	2	5·5	7·0	750	contracting
	Two-Wheeled.						
29	Fowler-Motor Plough ‖	14	2	4·0	5·0	1,100	cone
30	Moline Universal ‖	18	2	4·75	6·0	900	,,
31	Wyles Motor-Plough ‖	*11*	*1*	*5·0*	*6·0*	*1,000*	*cone*
	Attachment.						
32	Eros (Ford) ‖	(20)‡	(4)	(3·75)	(4.0)	—	—

Approximate and *estimated* figures are shown in italics.

* Compound: l.p. cylinder 6·375 in. bore.

† Two-cycle engine,

‡ The figures in brackets refer to the engine of the Ford Car.

(*concluded from opposite page*) TABLE 4.

Wheeled Tractors.

Speed m.p.h.			Total Weight.	Back Wheels.			Front Wheels.			Wheel Base.	Fuel.	No.
1st.	2nd.	3rd.		No.	Width.	Dia.	No.	Width.	Dia.			
			lb.		in.	in.		in.	in.	in.		
1·75	2·5	5·0	6,700	2	12	60	2	6	36	87	paraffin	1
2·37	4·0	none	5,200	2	10	60	2	4	46	92	,,	2
2·0	to	3·5	4,200	2	10	46	2	5	30	85	,,	3
2·0	to	3·5	3,800	2	10	46	2	5	30	85	,,	4
1·66	2·32	4·75	*5,500*	2	12	60	2	6	40	93	,,	5
2·5	4·0	none	5,350	2	10	60	2	4	46	90	,,	6
1·75	2·4	,,	2,450	2	12	48	2	6	32	80	,,	7
2·0	to	5·0	10,100	2	20	51	2	8	35	97·5	coal or coke	8
2·0	4·0	none	27,400	2	24	78	2	12	54	126	paraffin	9
2·0	4·0	,,	10,100	2	18	78	2	9	54	100	,,	10
2·0	4·5	,,	10,100	2	12	60	2	6	40	112	,,	11
2·0	2·75	,,	5,600	2	10	54	2	6	36	90	,,	12
2·0	none	,,	5,600	2	10	54	2	6	36	90	,,	13
1·5	2·75	6·75	2,580	2	12	42	2	5·25	28	63	,,	14
1·75	to	3·25	3,600	2	10	46	2	5	30	85	,,	15
2·5	none	none	4,800	2	10	52	2	5	28	90	,,	16
2·0	3·25	,,	4,000	2	10	60	2	5	36	100	,,	17
2·0	3·25	,,	4,300	2	10	60	2	5	36	100	,,	18
2·0	2·75	,,	6,850	2	10	54	2	6	36	88	,,	19
1·63	2·75	4·5	3,900	2	10	40	2	5	30	60	,,	20
2·5	none	none	4,800	2	12	56	1	6	32	96	,,	21
2·25	,,	,,	3,900	2	18 8	60 44	1	6	30	*100*	,,	22
2·38	,,	,,	3,000	2	12 6	50 40	1	6	22·5	*108*	,,	23
1·8	3·0	,,	6,600	1	26	64	2	6	33	98	,,	24
2·75	none	,,	3,700	2	10	56	1	5	29	99	,,	25
2·0	,,	,,	5,200	2	18	40	1	15	28	*100*	,,	26
2·5	3·8	,,	3,000	2	12	48	1	8	30	100	,,	27
2·41	none	,,	4,850	2	14 8	60 40	1	6	30	*110*	,,	28
1·55	2·22	,,	2,500	—	—	—	2	6	44	—	,,	29
1·0	to	3·0	2,800	—	—	—	2	8	52	—	petrol	30
1·75	*2·25*	*none*	*2,350*	—	—	—	2	*7*	*33*	—	,,	31
2·5	—	—	1,900§	2	8	38	—	—	—	—	,,	32

Approximate and *estimated* figures are shown in italics.

§ Of which the Ford Car accounts for 1,550 lb.

‖ These tractors took part in the Scottish Demonstration. It will be found that the figures obtained by the Author differ in many instances from those in the Scottish Report.

is self-steering, in other words the steering is of the reversible kind; a special feature is that the front wheel forks are capable of lateral adjustment so as to alter the tread of the tractor.

The chain-track is pivoted about the rear (driving) sprocket axle, and the frame is spring-supported from the track-frame at about the centre of the chain-track. The arrangement of carrying wheels and track-frame resembles that of the Killen-Strait tractor.

The particulars are as follows:—

Engine: horse-power 30; 4 cylinder, 4 cycle, bore 4 inches, stroke 6 inches, speed about 1,000 revolutions per minute, driving through a multiple-disk clutch.

Speeds: 1st, 2·35 miles per hour; 2nd, 3·5 miles per hour; reverse, 2·0 miles per hour.

The water and paraffin tank capacities are not given. The track supports, apart from the driving sprocket and the leading idler, consist of one pair of large diameter co-axial flanged wheels. The track is 15 inches wide, but the length in contact with the ground and the distribution of weight on the track and wheels are not given; the total weight is 5,600 lb., and the insistent weight is given as 4·5 lb. per square inch. The tractor has an overall length of 11·0 feet and is 8 feet 8 inches wide. The front (steering) wheels are both 7 inches wide by 30 inches in diameter; the track can be varied from 45 inches to 81 inches to allow for cultivating rows 36 inches to 48 inches wide. The clearance under the frame is abnormally high being 38 inches above the ground; particulars of the pitch of the chain-track are not given; the drawbar pull at the ploughing speed is given as 3,200 lb., which is equivalent to transmitting 20 h.p. through the drawbar, or a mechanical efficiency of 66 per cent. The drawbar pull amounts to 57·1 per cent. of the weight of the tractor.

Special precautions are taken to render the magneto waterproof and to protect the sparking plugs from rain or snow. The carburettor intake is fitted with an air filter, and the water system is stated also to be protected from dust. It is claimed that with a three-furrow plough a man does more than twice as much as he could do by horse-traction in the same time, while for such operations as cultivating and mowing he can do three times as

much as with the horses. For use with a binder a longer steering and control column can be substituted for the shorter one. An extension bracket can be fitted at the rear of the tractor to enable the driver to ride on the tractor if this is desired, but this requires two men, whereas the intention of the design is that both machine and implement shall be operated by one man.

Wheeled Tractors.

The Author has prepared Table 4 from data obtained direct from the manufacturers or agents in the majority of the cases tabulated. The Scottish demonstrations included also the Case and Saunderson-Universal four-wheel tractors, the Chase three-wheel tractor, and the Hodgson attachment for Ford cars. Five chain-track tractors were shown, namely the Bates Steel Mule, Burford-Cleveland, Creeping-Grip, Killen-Strait Model 3, and Martin Cultivator, all of which the Author has described.

At the Lectures given at Manchester, Leeds, Lincoln and Glasgow much interest was expressed relating to the various recent developments in light wheeled tractors for farm work in connexion with food production. These might be divided into four main classes: four-wheeled, three-wheeled, two-wheeled tractors, and tractor attachments for converting ordinary cars to haulage work. The first two groups were adapted for road-haulage, whereas the two-wheeled tractors were intended for use with a plough as a complete unit. There were at present well over fifty tractors of these various types many of which were but little known in Britain. The demonstrations made in Scotland, at Edinburgh, Glasgow, and Perth comprised a representative selection.*

* Highland and Agricultural Society of Scotland; Demonstration of Agricultural Tractors and Ploughs, October 1917. Since the Paper went to press a series of articles on British Agricultural Tractors has appeared in *The Engineer*, Vol. 124, pages 512–3, 533–5, 553–6, 562 and Vol. 125, pages 4–6, and 45–6. The descriptions include the Aveling and Porter, Burrell and Son, Foster, Garrett, Mann, McLaren and Ransomes, Sims and Jefferies, steam-tractors, as well as the Bumsted and Chandler, Crawley Agrimotor, Foster and Ivel internal-combustion engine tractors.]

(Mr. L. A. Legros.)

It would be seen from this very imperfect survey that the subject of wheeled agricultural tractors was one worthy of a Paper in itself.

Mr. ARTHUR AMOS, in replying to the criticisms on his Paper, wished to thank the members for the kindly manner in which it had been received. He entirely agreed with Mr. Watson's contentions that, given ordinary hard land, it was advantageous to have two of the tractor-wheels running in the furrow, not only because by this means the diagonal pull was avoided, but also because by this method, if the top surface was slightly greasy and the undersoil dry, a common condition in autumn, the tractor-wheels obtained a better foothold and less damage to texture resulted. He also agreed that it was desirable to consider the possibility of arranging a subsoiling attachment to, or in conjunction with, the plough, and this was of special importance if, as indicated above, two of the tractor-wheels ran in the furrow; in this case it was desirable that the subsoil after pressure by the wheels in the furrow should be loosened by some subsoiling implement immediately after the wheels had passed and before the next furrow was turned into the furrow. It was not necessary to subsoil land frequently, and he suggested that this single subsoil attachment following the wheels would be sufficient for the purpose. He did not agree with Mr. Watson, however, that $2\frac{1}{2}$ miles per hour would be the best rate at which tractors should work in all cases; in winter, when the ground was wet, he agreed that too rapid a speed left the furrows lying very irregularly, and rubbish was not so well buried, but for ploughing dry land, it was advantageous to break up the furrow, as with the digging type of plough, because this facilitated subsequent cultivation.

Professor Baker had asked him a question upon the damage done by the pressure of the wheels per square inch on the soil (page 165); he could best explain the damage by saying that when clay soil was worked or pressed, when wet, into a pasty condition (as the brickmaker worked his clay for brickmaking) the soil became impervious to air and water, and crops could not be successfully grown upon it—the texture was spoilt. It was important to remember that pressure upon the land might damage

the texture in two distinct layers of the soil; it might damage the surface soil only, as for example in autumn and early winter when rain might have fallen recently upon dry land, in this case comparatively small pressure per sq. inch would effect the damage, so that in this case the chain-track wheels were no better than others; or the damage might occur to the soil 3 or 4 inches below the surface, as for example in second ploughing or cultivating in spring after a spell of dry east wind, when the surface was dry, but the lower depths more or less sodden. In this case heavy pressure per square inch occasioned very serious damage, but a chain-track tractor might be able to pass over the surface with little damage to the lower depths. In agriculture there was a saying that "a March roll makes an April Fool," which meant that if one rolled clay land wheat when only the surface was dry too early in March, the texture of the lower depths would be damaged, and the wheat would look very yellow in April.

With many of Mr. McLaren's criticisms he cordially agreed, but considered that he had stated the case much too severely against the tractor by using Mr. Prothero's table of the work accomplished by government tractors in December and January, in criticism of the Author's statement that the motor tractor enabled the farmer to get his ploughing done quickly after harvest. There were many factors which contributed to put the work of the tractors, as shown in this Table, in the worst possible light; in December and January the land surface was rarely if ever in good order for ploughing, consequently, the tractor was handicapped to a very much greater extent than the number of hours lost, and for which Mr. McLaren allowed in his Table. The case was made still worse by the fact that in very many cases the tractors were actually at work when, owing to the condition of the land, they ought to have been idle. At this season in the year the days were short; in September and October, after harvest, there were about four more hours of daylight during which time an enterprising farmer would be able to keep his tractor running. The Government only commenced to obtain delivery of their tractors in quantity during the autumn and had been continually increasing their numbers

(Mr. Arthur Amos.)

during the season; they had had to train soldiers from the lower grades as drivers; consequently, during the period quoted, a large proportion of the drivers were mere novices, and it was a matter of common knowledge that tractors required skilled and intelligent driving in order to accomplish good work. Again, much ploughing time was lost under the Government scheme by the moving of the tractor and plough from one farm, at which it might have been working, to the next, which might be many miles away; not only was time lost on the road, but adjustments of wheels, etc., had also to be made; in the case of a privately-owned (by the farmer) tractor such loss of time would be reduced to a minimum. In place of the 6·5 acres per week, which Mr. McLaren suggested (page 171) as the average of what a tractor was capable in favourable weather, he would suggest that a good privately-owned tractor, driven by the farmer's son or other sympathetic driver, and working on average dry land after harvest, might be expected to accomplish on the average 20 acres per week with the plough. He fully agreed with Mr. McLaren that one of the most serious defects of the average motor tractor was the very rapid depreciation of the machine, a depreciation which tended to make the cost of tractor ploughing very heavy. When the Author in his original Paper stated that he knew of no tractor capable of dealing with the heaviest types of sun-baked clay, he should have qualified his statement by inserting the word "light" before tractor; he agreed that steam tractors of 5 to 6 tons were capable of accomplishing very valuable work on such clay land after harvest so long as the surface remained hard and dry.

Mr. Phillips had drawn attention to the fact that the Author was not alone in advocating one-way ploughing; he freely admitted it, but desired to emphasize that one-way ploughing was preferable from the farmer's point of view upon most land, and that this opened up one of the most promising opportunities for future development of the motor-tractor.

The Institution of Mechanical Engineers.

ANNUAL GENERAL MEETING.

February 1918.

The Seventy-First Annual General Meeting was held at The Institution of Civil Engineers, London, on Friday, 15th February 1918, at Six o'clock p.m.; Michael Longridge, Esq., *President*, in the Chair.

Before proceeding to business, the President said that since the last Meeting the Institution had lost another Member of the Council, Sir John Wolfe Barry. Sir John was known to all the members, and his works were known to most of them. Of these he thought the Engineering Standards Committee, its work and specifications, was his greatest achievement from the point of view of the Mechanical Engineer. No ordinary man could have overcome the prejudices and reconciled the many conflicting interests brought into activity by such a work which was destined to exercise a widespread and beneficial influence, not only on British Engineering, but he thought in America and on the Continent as well. In accordance with the wishes of the Council, he had written a letter of condolence to Sir John's widow and family, with whom he was sure all present heartily sympathized.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following eight Transferences had been made by the Council:—

Associate Members to Members.

Arthur, Henry Herbert, . . .	Carmarthen.
Ball, Edmund Bruce, ...	London.
Beynon, Herbert, ...	London.
Budge, John, ...	Coventry.
Forward, Ernest Alfred, . . .	London.
Irwin-Packington, Philip, Lieut., R.G.A., .	King's Lynn.
Symonds, Percival Herbert, . . .	Sheffield.
Walker, Edward George, Lieut., R.N.V.R.,	London.

The Annual Report of the Council for the year 1917 was then presented.

The President, in moving the adoption of the Annual Report and Statement of Accounts, said that the Report had been printed in the Journal of the Institution which had been sent to all the Members, so that he thought they would not wish him to read it at length. He would like, however, to bring before them the more essential paragraphs. The first related to the membership of the Institution, and it would be seen that, notwithstanding the War, the membership had increased. A diagram had been placed upon the wall which showed year by year the numbers of the various classes of Members and the total membership. The total membership since the beginning of the War had slightly declined until last year, but was now again on the up-grade. The increase in full Members during 1917 had been 32, and in Associate Members, 101, but unfortunately the number of Graduates showed a decrease of 72. That could hardly be otherwise, because so many of the younger men had gone to the War. The Institution now had some 6,300 Members, and out of those no less than 47 had received honours and recognition of their work from the King or from the French Government—44 from the King, and 3 from the French

Government. He thought the Institution could be congratulated upon that list, because the proportion of their Members whose names appeared in it was considerably higher than the general average for the country. Then came the list of those who had been taken away by death, and amongst them he would like to mention Mr. Westmacott, who was President of the Institution 36 years ago; Charles Hawksley, whose name would always be cherished in the Institution, and commemorated year by year by the Lecture which he founded, and by the Medal which bore his father's name; also Sir John Wolfe Barry, of whom he had already spoken. Not only the Institution but the whole profession of British engineering and the Empire were the poorer for the deaths of these men. Apart from that he thought there was nothing to regret; they had done their share of the world's work and they had gone to their rest full of years and honour. But while these names came naturally to their minds when counting up their losses, they must not forget the younger men whose lives had been cut short by battle, murder, and by sudden death, men who, although they had left few or no marks of their lives on the material world, had yet given imperishable examples of heroism and self-sacrifice which had a spiritual value, far higher than the value of any "works" they might have executed if they had remained alive. Those men should never be forgotten, and he hoped in a short time their names would be recorded in a permanent manner in the House of the Institution when they again had access to it, when the last sacrifice of the war had been exacted, and their roll of honour was complete. To turn from thoughts of those men to accounts seemed almost a sacrilege, but it had to be done.

The accounts of the Institution were given at the end of the Annual Report, but there was a short summary on pages 4 and 5 from which it would be seen that the total revenue had been £22,865, and the expenditure £22,701, including sums invested and put to reserve, so that the Institution had a balance of income over expenditure of £164. The form of the accounts had been somewhat altered. The Institution had hitherto had a fund called the "Sinking Fund for the Redemption of Debentures and the

(The President.)
Institution's Leasehold Property." That Fund contained several other funds, such as the General Reserve Fund and the Staff Pensions Fund, and the Chairman of the Finance Committee had spent much time and trouble in re-organizing the accounts so that the state of each of the four funds, namely, the "Debenture Redemption Sinking Fund," the "Leaseholds Amortisation Sinking Fund," the "Staff Pensions Fund," and the "General Reserve Fund," might be shown separately. The total assets of the Institution amounted to £144,000. Deducting from that £34,000 of debentures and £5,000 of debt still owing to Messrs. Williamson, other small liabilities, and £37,000 the sum of the four Funds mentioned, there still remained a credit balance of £66,503 9*s*. 2*d*., which was quite satisfactory.

Over 1,000 Members had been or were still on active service, and, with a view to helping them to find suitable employment on their return to civil life, the Council had prepared and issued to them, so far as their addresses were known, forms whereon they might record such particulars of their training and experience as would enable the Secretary to answer inquiries likely to bring together those who were offering, and those who were seeking, posts in engineering works or offices. The Council would be very glad a little later on for the co-operation of those who had berths to offer to the returning men.

The next paragraphs of the Report concerned the working of the Research Committees. Those Committees had not been so active as they generally were, because most of the Members were too fully employed upon war work to give time to anything else, also there had been much difficulty in getting materials for the construction of experimental apparatus.

The Alloys Research Committee had been occupied with investigations on light ternary alloys, and their Report would have been presented to the Institution, but for the fact that it contained matters which had to be kept secret at present in the public interest.

The Members of the Steam-Nozzles Research Committee had also been fully occupied in war work, and it had been impossible to construct apparatus to carry out tests.

The Hardness Tests Research Committee had made some experiments, and was now engaged upon a series of tests with special reference to the effects of variation of load and speed on rate of wear. Arising out of that Committee's work, Sir Robert Hadfield had placed in the hands of the Institution a sum of £200 to be awarded as a prize or prizes for a description of a new and accurate method of determining the hardness of metals, especially of metals of extreme hardness. That was a very important and difficult problem, and it was hoped suggestions for its solution would be received from Members.

The work of the Wire Ropes Research Committee had been delayed, not only by the pre-occupation of Members with war work, but by the prolonged illness of the Chairman, Mr. Pitt. He was very sorry to have to say that Mr. Pitt, who had been in ill-heath for some time, had recently been obliged to resign his membership of the Council and of the Committee. They all hoped for his speedy recovery and gave him their heartfelt sympathy. Dr. Hele-Shaw had kindly undertaken to act as Chairman in his absence. Little progress, however, must be expected for the present, because, as the subject of research did not immediately concern the problems of the war, and as materials could not be obtained for the required apparatus, the work was practically in abeyance.

Mr. Williamson had given the Institution £500 for engineering research, and a small Committee had been appointed to consider what research should be undertaken. Suggestions had been asked from Members and several had been made. After considering these, it was thought best to devote the money to a research to determine the best form and material for Pistons and Piston-Rings, especially for internal-combustion engines.

The next thing he would mention was the meeting of engineers and others interested in professional training, held at the Institution of Civil Engineers on 25th October last, and the appointment of a representative Committee to co-ordinate the work of schools and colleges with the training in the shops, so that parents might be told authoritatively what course their sons who intended to be Engineers should pursue at school and college, and where they

(The President.)
might obtain their practical training in shops and offices. The Committee would also try and guide the schools, especially secondary schools, into the right course to prepare men, not to make them specialists, but to enable them to obtain such knowledge as would form a solid foundation for their practical training. The Council was asked to appoint a member to serve on this Committee and did so. During the year information was received that an offer had been made by American manufacturers to Australia to take pupils, train them, and pay them a living wage during their apprenticeship. These proposals merited the most careful consideration of British Engineers, but beyond publishing them in the Institution Journal, the Council felt unable to take action. They were glad to know that the British Engineers' Association, a representative body composed largely of Manufacturing Engineers, was dealing with the matter.

There would be a meeting of the Benevolent Fund following the present Meeting, but as many Members might not be able to stay for it, he wished to say that the Fund was not supported as he thought it ought to be. Only 5 per cent. of the Members subscribed to it. The capital of the Fund amounted to less than £1 per Member of the Institution. The calls upon the Fund would, he feared, be heavy in the near future, and the present income inadequate to meet them as they should be met. As he said last year, it was the duty of Members to help the less fortunate of their own generation and not to rely upon the interest of invested capital accumulated by the gifts of a comparatively small number of generous men. He had received a letter from a member of the Fund suggesting that a levy of 5*s*. should be made upon every Member of the Institution. The Council had no power to do that, and, if it had, he should not ask them to exercise it. The money ought to come not by compulsion but as a free gift. Five shillings was not a large amount, but if every Member gave it the revenue obtained would be about £1,500 a year, a sum which would enable the Institution to save a large amount of suffering which individual Members would only be too ready to relieve if they knew the greatness of the need. At the present time that could not be done. It had been said that the Committee might do more than it was

doing, but, in the uncertainty as to what the future income would amount to, and the great probability of having to meet large claims, the Committee of Management felt that they ought to use part of the present income to accumulate a reserve. The Report was now before the Members, and he would be very happy to hear, and, if possible, answer any questions that might be put.

Mr. Daniel Adamson wished to support the adoption of the Report, and to take the opportunity of thanking the Finance Committee and the Chairman for the alteration in the form of the Revenue Account. It was a most desirable change. He believed he mentioned it a year ago, and for what they were worth he would like to offer his thanks to the Finance Committee, and especially its Chairman for the trouble that had been taken.

With regard to the question of Australian apprentices which had been referred to the British Engineers' Association, that Association was dealing with the matter, but the time taken for letters to pass was considerable and therefore progress was slow. He would suggest that the Institution should not overlook the fact, because even the British Engineers' Association might forget it, or not appreciate its importance.

With reference to the resignation of Mr. Pitt from the Chairmanship of the Wire Ropes Research Committee, he took it the Members would express their thanks in some way to him for the hard work he had put into that Committee already. Although nothing had appeared, a great deal of the spade work had been done under his guidance.

With regard to the Benevolent Fund, he would like to support what the President had said. The chief feature of the Fund was that it was managed by the Members of the Institution for the benefit of Members. The cost of management was small. Many applications for subscriptions were received from other directions, and anyone looking at the balance sheets of many of those Funds would find the expenses of management were very high, but that did not apply to the Benevolent Fund. No one in the industry knew when he might be in such a position as to have to ask for

(Mr. Daniel Adamson.)

help from such a Fund, and if any one could afford to give even a small sum it would be acceptable. It was surprising how small sums mounted up if they were sufficiently numerous. The expenses, as he had said, were so small that Members could be certain the money went to the object it was given for, and also to men who were engineers and with whose dependents the Members would have every sympathy.

On the motion of The PRESIDENT, seconded by Mr. Adamson, the Report was adopted.

The SECRETARY read the list of Awards since 1914 of the THOMAS HAWKSLEY GOLD MEDAL, as follows:—

ROBERT S. WHIPPLE, 1914.
Professeur EDOUARD SAUVAGE, } 1915.
ANATOLE MALLET, }
Professor H. L. CALLENDAR, F.R.S., 1916.
DANIEL ADAMSON, 1917.
A. A. GRIFFITH, M.Eng., } 1918.
G. I. TAYLOR, M.A., }

The PRESIDENT, in presenting the Thomas Hawksley Medal to Mr. Whipple, said it should have been of gold, but as gold was unobtainable at the present time it had been struck in bronze. In due time it would be replaced by a gold one. There were also large-scale copies of the obverse and reverse faces of the Medal with which the recipient could decorate the walls of his home or office. The President explained that Professor Sauvage could not be present, as he was serving in the French Artillery, and the Medal would also be sent to M. Mallet. Professor Callendar was not able to be present.

In handing the Medal for 1917 to Mr. Daniel Adamson, the President said that the personal friendship between Mr. Adamson and himself made the duty of presenting it an especially pleasant one. The President explained that Mr. Griffith and Mr. Taylor also were not able to be present.

The Secretary said the Institution's Examinations were held in October. A prize of £5 was awarded to Mr. C. T. Glass-Hooper in the Associate Membership Examination, and a prize of £3 to Mr. A. L. Williams in the Graduateship Examination.

The President, in presenting the prize volumes to Mr. Glass-Hooper, said he was pleased to do so, and he hoped that they marked only the beginning of a very successful career. He also congratulated Mr. Glass-Hooper on having passed his Associate Membership Examination at an early age.

The President also presented a prize of £3 in the form of books, etc., to Mr. A. L. Williams for good work done in the Graduateship Examination.

The President said that out of the Sir Robert Hadfield Prize Fund, a sum of £25 had been awarded to Professor C. A. Edwards, D.Sc., and Mr. F. W. Willis, B.Sc., for their joint research dealing with "A Law governing the Resistance to Penetration of Metals which are capable of Plastic Deformation," and "A new Hardness Scale in Fundamental Units."

The President reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council, and that the following were found to be duly elected:—

President.

Michael Longridge, ...	London.

Vice-Presidents.

William H. Allen, ...	Bedford.
J. Rossiter Hoyle, ...	Sheffield.

MEMBERS OF COUNCIL.

DANIEL ADAMSON,	Hyde.
Sir HENRY FOWLER, K.B.E.,	Derby.
EDWARD HOPKINSON, D.Sc.,	Manchester.
HENRY A. IVATT,	Haywards Heath.
Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S.,	Bromley, Kent.
JAMES W. RESTLER,	London.
RICHARD WILLIAMSON,	Workington.

The Council for the present year is therefore as follows:—

PRESIDENT.

MICHAEL LONGRIDGE,	London.

PAST-PRESIDENTS.

Sir JOHN A. F. ASPINALL, M.Eng.,	Manchester.
Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S.,	London.
WILLIAM H. MAW, LL.D.,	London.
E. WINDSOR RICHARDS,	Caerleon.
W. CAWTHORNE UNWIN, LL.D., F.R.S.,	London.
J. HARTLEY WICKSTEED,	Leeds.

VICE-PRESIDENTS.

WILLIAM H. ALLEN,	Bedford.
Sir DUGALD CLERK, K.B.E., D.Sc., F.R.S.,	London.
HENRY DAVEY,	Ewell.
Sir ROBERT A. HADFIELD, Bart., D.Sc., D.Met., F.R.S.,	Sheffield.
J. ROSSITER HOYLE,	Sheffield.
MARK H. ROBINSON,	London.

MEMBERS OF COUNCIL.

DANIEL ADAMSON,	Hyde.
ARCHIBALD BARR, LL.D., D.Sc.,	Glasgow.

Sir A. Trevor Dawson,	London.
John Dewrance,	London.
Sir Henry Fowler, K.B.E.,	Derby.
H. S. Hele-Shaw, LL.D., D.Sc., F.R.S.,	London.
Edward Hopkinson, D.Sc.,	Manchester.
George Hughes,	Horwich.
Henry A. Ivatt,	Haywards Heath.
Bowman Malcolm,	Belfast.
Robert Matthews,	Manchester.
Donald B. Morison,	Hartlepool.
Sir Gerard A. Muntz, Bart.,	Birmingham.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S.,	Bromley, Kent.
William H. Patchell,	London.
Sir Vincent L. Raven, K.B.E.,	London.
William Reavell,	Ipswich.
James W. Restler,	London.
Captain H. Riall Sankey, C.B., R.E., ret.,	London.
Richard Williamson,	Workington.
Wilson Worsdell,	Ascot.

Colonel R. E. B. Crompton, C.B., R.E. (T.), moved the following Resolution :—

"That Mr. Raymond Crane, F.C.A., 46–47 London Wall, London, be reappointed to audit the accounts of the Institution for the present year, at a remuneration of Fifty Guineas."

Mr. E. R. Dolby seconded the Motion.

The President said the Auditor in the past year had had a great deal of extra work, owing to the changes made in the form of

the accounts, and he deserved a special vote of thanks for the trouble he had taken in putting those changes into shape.

The Resolution was carried unanimously.

The Discussion was then commenced on the two Papers which had been read at the January Meeting, namely:—

"Utility of Motor-Tractors for Tillage Purposes"; by ARTHUR AMOS, M.A., of the School of Agriculture, University of Cambridge.

"Traction on bad Roads or Land"; by L. A. LEGROS, of Acton, *Member*.

The Meeting terminated at Half-past Seven o'clock. The attendance was 75 Members and 35 Visitors.

The Institution of Mechanical Engineers.

PROCEEDINGS.

March 1918.

An Ordinary General Meeting was held at The Institution of Civil Engineers, London, on Friday, 15th March 1918, at Six o'clock p.m.; Michael Longridge, Esq., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following eighty Candidates had been duly elected:—

MEMBERS.

Austin, Sir Herbert,	Birmingham.
Barnes, William,	Lincoln.
Bircham, Francis Richard Samuel, Temp. Com., R.N.V.R.,	London.
Burrows, Stephen Henderson,	Stalybridge.
Carruthers, John, Lieut.,	London.
Colley, Leo Joseph St. John, Major, R.E.,	Stockport.
Davis, Cyril George,	Luton.
Despaigne, Henri,	London.
Douglas, Clifford Hugh, Major, R.F.C. (T.F.),	Richmond, Surrey.
Eaves, William,	Sheffield.
Firth, Wybert,	Consett.
Géraki, Jean,	Paris.

Murgatroyd, Frank,	Huddersfield.
Neill, Robert,	Sheffield.
Nichols, Thomas Winter,	London.
Scott-Robinson, Michael.	London.
Service, William,	Sarawak.
Smith, Harry John,	Hanyang, China.
Stanley, Charles,	London.
Stansfeld, John,	Leeds.

ASSOCIATE MEMBERS.

Abbott, John,	London.
Acland, Herbert Arthur Dyke,	London.
Ash, Sydney Hubert, Major, R.E. (S.R.),	B.E.F.
Attack, Arthur Marshall,	Reading.
Ayres, George Herbert,	Birmingham.
Bailey James,	Newcastle-on-Tyne.
Baker, John Austin, Lieut. (W.), A.S.C.,	France.
Brown, George William,	Belfast.
Brown, Thomas Arthur,	Woolwich.
Buchanan, John, Artificer Engineer.	H.M.S. "Heather."
Burness, John Young,	Motherwell.
Cassells, John George,	Bradford.
Crewe, William Archibald,	Lincoln.
Derbyshire, Robert Knight,	Manchester.
Edwards, George Herbert,	Edinburgh.
Gough, George Nestor,	Birmingham.
Griffiths, Reginald St. Aubyn, Capt., R.E.,	B.S.F.
Harben, John Edward, Lieut., R.E.,	B.E.F.
Harley, George,	Cowley, Oxon.
Hodgson, Harry,	London.
King, Ernest Platten,	London.
Lane, Frederick Tremayne,	Woolwich.
Lee, John Albert,	Bombay.
MacArthur, William White,	Lincoln.
McLusky, John Wauchope,	Blackburn.
Marris, Reginald Willows Hildyard,	Rangoon.
Mattock, William George Herbert,	London.
May, Arthur Gordon,	London.
Morgan, Thomas Henry,	Dornock.
Munro, Andrew Ross,	Brisbane.
Ormesher, Arthur Harrison, Lieut. Y. & L. Regt.,	Osborne, I.O.W.
Pratt, Adolf Camden,	Bristol.
Ratcliffe, Robert Alfred,	London.
Reid, Francis Heine,	Devonport.
Richards, Frederic Henry, Lieut., R.E.,	Leicester.

Richards, Herbert Edward,	Bristol.
Richardson, Joseph James,	Birmingham.
Smith, Alexander Runcie,	Aberdeen.
Spedding, John James,	Oakengates.
Swindin, Norman,	London.
Thomas, Harold Ernest Ray,	Stockport.
Thomas, Leonard Howard,	Birmingham.
Thwaites, Richard Alan Stuart,	Bedford.
Turner, William Charles,	Birmingham.
Vickers, George Boardman,	Bolton.
Ward, Arthur Kingsley,	Sunderland.
Wildy, Eric Lawrence,	London.
Wolsey, George, 2nd Lieut., R.E.,	London.
Wood, Alfred James,	Birmingham.
Yapp, Robert Harold,	Bath.
Young, Edgar Chivers,	Leicester.

ASSOCIATES.

Forrester, Harris Albert,	Barking.
Hooper, Ernest Frederick,	Newcastle-on-Tyne.
MacKenzie, Murdoch MacKenzie Hodson,	Ipswich.

GRADUATES.

Churchman, Harold, Sub-Lieut., R.N.V.R.,	London.
Creese, Lyell Frank, Eng. Lieut., R.N.V.R.,	Whetstone.
Horton, Herbert,	Derby.
Lyen, Oswald Yet San,	Teddington.
Marsden, Ernest, Sub-Lieut., R.N.V.R.,	London.
Sheldrick, John Engledow,	Brighton.

The President announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

Laity, Harry Thompson,	Natal.
Midgley, Harold Edward,	Erith.
Polden, Francis Charles,	London.
Sutherland, Kenneth Wallace,	New York.

The President said he regretted to have to make an announcement which he thought the Members would receive with great regret and with some justifiable indignation. For some inscrutable reason the Special Intelligence Branch of the Ministry of Munitions, to whom the Papers had to be referred for censorship, had forbidden the reading of Mr. Morgan's Paper. He was very well aware of the critical relations which existed between the A.S.E. and the Government, and of the absolute necessity for suppressing any document or discussion which might by any possibility aggravate the differences which existed or create suspicion that engineering employers intended to break the pledges they had given without the men's consent. Had the Paper suggested anything of the kind it would never have been accepted by the Council; on the contrary, it was carefully read and edited by Dr. Maw and himself, and any expression that might have been twisted by mischief-makers to create misunderstanding had been carefully removed, so that in the approved form the Paper contained nothing but a record of what had been done during the War in the employment of women in munition factories. The Paper was sent to the Ministry of Munitions on the 2nd inst., with a notification that it was intended to be read at that Meeting. Since then, the Secretary had been in constant communication with the Department, by telephone, by letter, and in person, without being able to ascertain what the decision would be. On Tuesday the Secretary was informed unofficially by telephone that it was probable that the Paper could not be read. The information reached him (the President) on Wednesday morning, and he at once wrote to the Department asking to be informed officially if the information which had reached the Secretary was correct, and if so, what portions of the Paper were objected to, and whether, if these portions were deleted, the rest of the Paper could be read. He sent that letter by messenger and requested a reply by messenger, pointing out the great inconvenience caused by the delay. On Wednesday morning the Secretary was informed by letter from the Special Intelligence Branch that the Ministry of Munitions could not consent to the publication of the Paper.

On the same morning he (the President) received a letter to the effect that the objection to Mr. Morgan's Paper was to its general tenor rather than to any particular portions, and that "the question as to whether Mr. Morgan should have permission to read the Paper is one for the Ministry of National Service, and it will be necessary for you to consult them if you desire to be informed officially as to their attitude."

That was the whole of the case. Without reading the Paper the Members could not judge whether the Ministry had any just grounds for withholding a valuable record of experience gained from an Institution composed of men who he would have thought would have been entitled to receive it in the public interest. Neither could they decide why the Ministry of Munitions refused their consent to the reading of the Paper, and at the same time informed him that application for permission to read the Paper was a question for the Ministry of National Service, but this he thought they would decide, that the official who, knowing all the circumstances, kept back his decision for ten days had been guilty of great discourtesy towards the Institution, a representative body of the most important profession and industry in the country and numbering among its Members men who had done as much or more than the members of any other body, except our fighting men, to bring this great mechanical war to a happy termination.*

---

* The President thinks it right to state that before Mr. Morgan's Paper was submitted to the Council information had been received indirectly that the Author had obtained permission from his superior officer at the Ministry of Munitions to write a Paper on the work of Women in Munition Works. This information has been confirmed by the Author since the Meeting, and supplemented by a statement that the Paper was submitted to the Department of the Ministry of National Service to which the Author had been transferred, and had been approved by that Department subject to certain revisions which were duly made in the proof.

The following Paper was read and partly discussed :—

"The Employment of Women in Munition Factories";
by Miss O. E. MONKHOUSE, M.B.E., B.A. (LOND.).

The Meeting terminated at a Half past Seven o'clock. The attendance was 81 Members and 51 Visitors.

THE EMPLOYMENT OF WOMEN IN MUNITION FACTORIES.

By Miss O. E. MONKHOUSE, M.B.E., B.A. (Lond.).

Introduction—At the outset the Author wishes to acknowledge the compliment accorded to her by this Institution of being asked to give her views on the employment of Women in Engineering Works. Her appreciation is increased in so far as the request preceded the passage through Parliament of the measure giving the franchise to women.

At the beginning of the war it was an exceptional thing for women to be employed as general machinists and fitters in engineering shops, but the demand for a greatly increased supply of labour of all kinds for munitions production, and at the same time the necessity for conserving the man-power of the country to the fullest extent, made it necessary for the Government to turn to the largest source of supply of unskilled labour, namely, women. The successful employment of women in engineering works depends not only on the unskilled woman, but in an almost equal degree on the skilled man, and the employer.

[The I.Mech.E.]

The Employer.—The successful employer of women labour faces the question of dilution squarely, and recognizes at the outset that the psychology of the woman worker is different from that of the man. Next he fixes on work suitable for his new type of employee, and then determines the quickest and easiest way to train her in the work. He assures himself of the extent to which the men will co-operate, and is always careful to provide suitable shop conditions and plant, etc. Having made these preliminary arrangements, he realizes the necessity for carefully choosing the right class of labour, and his next step is to appoint a woman of experience to engage and look after the women, and to select as their technical overseer a foreman who he knows is sympathetic with his new venture.

The Skilled Man.—The skilled men have to do the technical training, and have to use all their brains and skill in order to train inexperienced women. They have to sectionalize work, adapt machinery, and simplify operations so as to make it possible to employ women. In their hands is largely the power to oppose and retard all progress by women on skilled work, because at the outset hardly a single woman is in a position to know when obstacles are being placed in her way. She perforce has to rely entirely on their generosity, and her position in engineering shops to-day shows that she has not relied in vain.

On the other hand, it must be remembered that every man does not make a teacher, and that every teacher of men is not necessarily a suitable teacher of women. Thus the unequal success of women in different shops is due in a measure to this cause as well as to antagonism on the part of the men.

The Unskilled Woman. — The successful woman-worker in an engineering works has a great deal to learn, because in addition to learning her work she has to acquire correct work habits, and face obstacles both necessary and unnecessary which are constantly put in the way of her becoming efficient.

There are, however, three grades of unskilled women who must be taken into account :—

(1) The educated type.
(2) The domestic type.
(3) The ordinary factory type.

The educated type come with trained brains; they know how to learn and how to apply their knowledge. They probably have mathematical training and can be taught in a very short time how to use a slide-rule, a micrometer, and other gauges. Fine limits present no difficulty to them, and in a sense they may be regarded as already half educated for the better class of engineering work.

The second type, namely, the domestic type, drawn mostly from the daughters of small tradesmen, generally have a good deal of sound common sense, are reliable, and enjoy, and so aim at securing, some position of authority. Such people train quite readily into good charge-hands and forewomen.

The factory type are different from either of the other two—they are mainly concerned with making as much money as they can, and preferably on piece-work. For the most part they resent being put on to a new operation because, every time they learn anything fresh, it means a temporary set-back in wages. It has therefore been found best to employ such workers on purely unskilled work of a repetition nature.

But no matter what the type of unskilled women, it must always be borne in mind that their success depends largely on the judgment of the management in selecting a good class of women labour. At the present moment there are, roughly speaking, close on 1,000,000 women employed on the production of munitions of war.

The introduction of all these women into engineering shops meant that a great many difficulties had to be overcome. These may be briefly summarized as follows:—

(1) A very large proportion of the women employed not being accustomed to factory life and discipline.

(2) The majority of works managers and foremen not being accustomed to managing women workers.

(3) The shop conditions for the most part planned with a view to the employment of men.

(4) The use of the machinery to which women have hitherto been unaccustomed.

(5) The difficulties of maintaining discipline in a mixed shop and in entirely female shops staffed by women of no previous factory experience.

(6) The long hours.

(7) The question of physical strength.

Many of these difficulties have been overcome by careful selection of suitable work, a careful choice of labour, proper shop organization, conforming to definite welfare standards, installing or adapting plant suitable to women's use, supplying proper training facilities, sub-dividing skilled work and adapting the hours of employment in accordance with the class of work done.

How Women have reached their present Skill.—At the stage which women have reached at the present moment in engineering, nothing but harm can be done by praising their powers too highly, but there are many individual cases where women have shown very great ability, and have acquired a knowledge of a certain branch of engineering work in excess of what would have been learnt by an apprentice in the same period under pre-war conditions. This state of affairs may be attributed very largely to three causes :—(1) Women have been definitely taught, whereas the apprentices had to pick up their trade. (2) Women have, for the most part, been intensively taught everything in the shop itself under production conditions rather than in the school. (3) The conditions of the time have actuated and spurred on everybody to greater effort, from patriotic motives.

Training of Women Workers.—There is little doubt that the advantage of getting their training under production conditions has been very largely instrumental in considerably speeding up women's training, and the Author would like now to consider some of the methods in use for training women workers.

Women Trained in Works in a Separate Shop.—It is extremely

difficult to start women in the same shop with men, unless the latter are in sympathy with the movement, and experience has proved that the only satisfactory way is to start women in a shop by themselves under a sympathetic foreman until they have proved themselves. In illustration of this the Author can quote a firm who, up to last April, had no women bench-fitters on aircraft work. They have adopted the above plan, and there are now 200 women fitters in the shop controlled by women charge-hands, all doing exceedingly well.

Overcoming of incredulity on part of Management.—Another type of case which should be mentioned is that of firms who cannot believe that women can do anything but purely repetition work, and regard a woman fitter, tool-turner, or tool-setter as an impossibility. It therefore is no use telling them that they must upgrade their women on to better work; they have to be shown that women are available in numbers who can do such work. In such case the Ministry often sends to the firm an expert woman demonstrator. She will first of all do the job herself in the shop to prove its practicability, and she will then continue to assist the firm by training some of their best operators or helping them to select others who are suitable. There are many firms which, having been assisted in this way, have become some of the most successfully worked shops in the country, not only from the point of view of percentage of women labour but of record output as well.

Other successful methods of training Women Workers.—It would take up too much time to go through at length all the various methods which have had to be adopted in order to make women efficient in the shortest possible time. Government training schools have done much by supplying a nucleus of semi-trained labour to shops desiring either to make a start with women labour or to introduce women on to some new class of work. Just a few large firms have done the ideal thing and set up their own training schools, from which they have a continual flow of semi-trained labour always ready to draw upon.

Characteristics of Women.—All consideration of women's work must be accompanied by a careful appreciation of the mental and physical characteristics of women. They have shown great adaptability and natural skill in successfully undertaking work of an entirely new character, but the varying degrees of success points to the necessity for thoroughly understanding their peculiar temperament if the best results are to be obtained.

Shop Organization.—Firms, who with male labour have been thoroughly successful, have failed when forced to employ women labour, thus proving that they did not understand their new employees. Other managers have not recognized their own failings clearly, and numerous cases can be quoted where the want of success of women labour has been traced to defective shop organization. By this term is meant the question of supervision and direction of the work in the factory—work usually performed by foremen and male charge hands. A foreman may be an admirable foreman of men, and at the same time an unsuitable foreman for women, apart from the question of his technical ability. There is no doubt that women do need special management, and it is folly to disregard the human element, as some do, by asserting that if women are to be employed on men's work, they must be treated the same as men. In one sense this is true. Discipline and strict adherence to work should be expected from women just as much as from men. As a rule men are either too lenient or too stern in their treatment of women, or too busy to study their peculiarities, and experience has shown that women should be controlled and organized by their own sex if the best results are to be obtained.

Shop organization, however, even when performed by women, may be quite unsuccessful if proper judgment is not used when selecting people for this work, and this brings up the general question of the choice of woman labour.

Choice of Labour.—There is no doubt that generally speaking a woman is a better judge of a woman than a man, and successful

firms have realized this and have appointed an experienced woman supervisor, to be responsible for engaging all their women labour. Very recently a case came to the Author's notice of a factory where one side of the labour was chosen by a woman and the rest by a man. There was great complaint of the efficiency of the latter, but none of the former. Investigation showed the cause that those women who were "turned down" by the woman supervisor were generally engaged by the man.

Ordinary Labour.—In the choice of ordinary operatives, stability of character and suitable physique must be the main considerations, but different characteristics must be taken into account when choosing forewomen and charge-hands. It is most essential that such people should have shop experience coupled with a certain amount of technical knowledge, and a thorough knowledge of how to manage women, and ability to hold their own in the shop. Women taking up this work must have tact and discretion, and the necessary power to enable them to work in harmony with the shop manager, whose authority should not be interfered with. Generally speaking, the most successful forewomen and charge-hands have been drawn from the more educated classes. For it must be remembered that women as a whole have been introduced very quickly, in very large numbers, without proper training or proper discipline, and it needs someone with powers of leadership and organization to get the women labour going on a proper footing.

Welfare.—Placing in factories in such large numbers women, many of whom have never been accustomed to factory life or conditions, has also called for special consideration of welfare conditions on the part of the employers. In considering this question two points of view must be taken in account: (1) Effect of Welfare on Production; and (2) Effect of Welfare on the Race.

Effect of Welfare on Production.—Employers have now for the most part fully realized that to give their women good welfare conditions is a sound business proposition. Without such provision

they cannot get a good class of labour. The unwonted heavy muscular effort and constant strain through which they are working makes it essential that their off times should be restful, if good work is to be done after the break. Good canteen accommodation also is most important, and there have been cases where managers have found that to provide one good meal a day free of cost has been more than repaid to them in output.

Welfare on the Race.—But quite apart from the effect of welfare on production is the effect of welfare on the race. From the national point of view this is the most important aspect to consider. For this reason the Health of Munition Workers' Committee was formed, whose special care was to safeguard any deterioration of the race which might perhaps accrue from women being compelled to work in all great industries. They have considered carefully (1) the hours of work; (2) rest periods and provision for meals; (3) sanitary conditions of the factory; (4) physical condition of women workers; (5) questions of management and supervision.

Hours of Work.—With regard to hours of work, experience has shown that a reasonably short shift is the most successful, producing less industrial fatigue as shown by few accidents, better timekeeping, and undiminished capacity of the worker towards the end of the shift so that a better average output is maintained. Another point in favour of shorter hours is the fact that a better class of labour is tempted to join the ranks of munition workers.

The other problems the Committee have considered in full detail, and the result of their investigation has shown that the nation is under a definite obligation to consider women's health and comfort in the factories if they are to protect and safeguard their position as the mothers of the race. Experience has shown that wherever there has been proper consideration for women's welfare in factories that there has been not only no decrease in healthy physical development, but a decided increase in mental capacity. It has been an enormous advantage for women to have had this opening into a wider field

of skilled and semi-skilled work, and the country has benefited by a tremendous increase of industrial efficiency.

It must be remembered that a woman's work is not ended when she leaves the factory. On her largely depends the life and happiness of the nation in creating and developing a happy healthy family life, and it is her privilege to care for the physical and spiritual welfare of the race. Added industrial efficiency therefore at the expense of women fulfilling their primary duties in their homes and to their children cannot result in anything but national disaster, and it is a sacred duty of the State to ensure that women are only used as wealth producers in so far as it does not affect the healthy development of the race.

Discussion on Friday, 15th March 1918.

Miss Monkhouse said that, though her remarks were based on the experience of her work in the employment of women in munition factories, she spoke that evening as a private individual and in no sense in an official capacity.

The President heartily congratulated Miss Monkhouse on the reception which she and her Paper had received. He placed her first because the event of the evening was the appearance of a lady as the Author and reader of a Paper at a Meeting of the Institution of Mechanical Engineers. It was doubtless one of the unforeseen consequences of the war, but it was also a sign of the times. He put her Paper second because there was not much to differentiate it from the ordinary run of Papers that were read before the

Institution ; it was on the same level. In giving this verdict, he hoped Miss Monkhouse would not feel that he was treating her hardly. The Paper dealt succinctly from a woman's point of view with some of the difficulties attending the introduction of women's labour in engineering works. It told something of the special arrangements which had to be made for their health and comfort, and something of the special organization which was required to adapt manufacturing processes to women's labour and to the capacity or incapacity of women, he did not know which to say.

The Paper also touched upon the much more important question of the effect of this kind of work on the future of our race, and upon the comfort and happiness of the homes from which these women came. That side of the question was very apt to be overlooked and thrown into the background, and he earnestly commended the last paragraph of Miss Monkhouse's Paper to those of her sisters who were clamouring for the work and privileges of men, despising the far higher work which nature had allotted to them, and the great privileges which their womanhood conferred. All these subjects afforded ample opportunity for discussion which he hoped the members would take advantage of. At the same time he hoped that nothing would be said to aggravate the sexual and industrial difficulties which the nation would shortly be called upon to overcome. They wanted the results of experience from those who knew, suggestions as to the inferences to be drawn from that experience from those who thought, but let there be no controversy as to the right of women to take men's work or as to the policy of enforcing the pledges given by the Employers to the Trade Unions. The Employers would keep those pledges until the Unions released them and substituted agreements more beneficial to both sides. Those agreements must be the work of the Employers and Employed themselves, and suggestions and interference from outside bodies would do no good and might do irreparable harm. There were several lady visitors present and he would very much like one of them to open the discussion.

As no lady indicated her intention to speak, the President called upon Mr. Charles Wicksteed.

Mr. Charles Wicksteed said he would deal with this matter as a man, and an engineer, not only from the point of view of the work which women had done, but as to their future in the engineering trade. His own works were small and he had only 100 girls in his employ, the town having about 30,000 inhabitants. He would state his experience for what it was worth.

He had provided lavatories with soft and hot water to wash with, as no girls had been employed in Northamptonshire in the engineering trade before, and he did not wish them to be laughed at for going through the town with dirty hands. As soon as he could, he provided them with a splendid canteen; and a dormitory for the country girls. They were happy and healthy and told him they had improved in health and strength since they had been with him. He merely mentioned these facts to show that as far as he knew they were being employed under the most favourable conditions.

They were engaged in manufacturing 4·5- and 6-inch shells complete, except the copper bands. It had given him much pleasure and also much trouble in getting the place satisfactorily to work. Considering what could be reasonably expected of the girls they had done exceedingly well, and it was one of the happiest experiences of his life to see how quickly they took to the work, how neatly they handled the shells, and the zest and interest they had shown in their work. He had had all sorts of troubles, however, apart from the troubles of the Government inspection and the inexperience of his staff and the frailties and complete inexperience of the girls. He hoped his foremen never swore, but one of them came to him one day and said, "If I had known as much about women before I was married as I do now, I do not believe that I should ever have got married." For some time the things the girls were capable of doing were incredible. He often could not possibly conceive how they managed to get wrong. Traverses were left in and lathes broken wholesale, until in his aggravation he had said one day, that although it was difficult to make a thing "fool proof," it was impossible to make it "girl proof." They had been improving ever since, however. Belt traverses had replaced

gear traverses, and better equipment, better discipline and more experience had produced better work. Each girl turned out two 4·5-inch shells complete every day or one 6-inch shell complete with the noses. The wasters were less than 1 per cent., and things were going on as nicely now as they formerly went wrong. He worked three shifts and only had one tool-setter for twenty-five girls. At night there was only a labourer and a tool-setter in the place, and yet the night shift turned out within 5 per cent. as much work as the day shifts.

One of the troubles that continued was the bad time-keeping of the girls. He had on an average two girls absent in every shift; if this were even it would matter little, but sometimes there were five or seven absent, making it quite impossible to keep going certain machines difficult to work. He found the women lost four times as much time as the men did, and fifty out of the 100 left in twelve months, against ten out of the 100 in the case of the men. This comparatively bad time-keeping of the women was inevitable unless one were to assume:—

First: That they were as strong as men.

Second: That they must neglect their domestic duties at home and the care for their own constitution, or as Miss Monkhouse expressed it, "The welfare of the race." The girls were not so truthful, or so honest, or so reliable as the men, and now and then they seemed to lose themselves.

Mr. William H. Allen asked if Mr. Wicksteed was alluding to his own girls.

Mr. Wicksteed replied in the affirmative, and said he had heard rumours that girls in other works were no better.

He had no sympathy with the nonsense published in the newspapers about the prodigies women had become, and how they could be taught in a few weeks that which had taken many years for a man to learn. Miss Monkhouse said, that "the tool-setter was as important as the woman worker." She might have said, "Without the skilled tool-setter the works would be closed in a

day, and without the skilled mechanic behind the tool-setter they would be closed in a week." The fact of the matter was, the girls were not engineers at all, they were only tool attendants; and when it came to the question as to whether they ever would be suitable for the engineering trade, he had come to the conclusion that, although women would always be able to do the fringes of engineering work to advantage, such as duplicate work involving light inexpensive machinery or hand work, they were entirely unsuited for engineering proper. Engineering required a long training that could never be given to women. If six boy apprentices were taken, five of them would go through their time; if six girls were apprenticed none of them would. They would tire of the work, their mothers would take them away for some unknown reason; the doctors would say the work did not suit them; their sister-in-law would want their help or the mother would be ill; they would get married, or leave for various other reasons. The one thing that would be certain would be, that none of them would go through their apprenticeship. The present girls put on at high wage to work a single operation on a special machine had no chance of becoming engineers. Contrast her position with a boy who was sent into the shop at a most receptive age at a nominal wage, and put on a simple job on his own account, or as a help to a man—his eyes open desiring to be doing and attaining something. He, naturally, soon became self-helpful and experienced in the rudiments of engineering, on which foundation he rose step by step after years.

In conclusion, Mr. Wicksteed said that men need not be afraid of the competition of women as engineers, and that he was convinced that the girls would all be dispensed with after the War; so convinced was he of this, that he was co-operating with the girls to provide them with a reasonable weekly allowance for the time of unemployment that might follow their dismissal. The girls paid 3*s*. a week and the firm contributed a like amount. The unemployment allowance being from 10*s*. to 15*s*. a week as desired, so long as the fund lasted.

Mr. Robert B. Creak said there were three points in the Paper

(Mr. Robert B. Creak.)

which had struck him as important. The first was that Miss Monkhouse had mentioned the value of training schools in bringing women to a high point of efficiency. If that were so in the case of women, might it not be much more so in the case of boys, after what they had heard from the last speaker as to the natural capacity for mechanics of boys versus girls. The second point was the value that had been found in the employment of women on shorter shifts. He was inclined to think that the same value in the matter of increased output would also occur if men's shifts were somewhat shorter, especially in the early morning. The third point that had come out in the Paper was the value from a money-making, and an output point of view of welfare work. Here again he thought the same would prove to apply to men's work as well as to women's.

Mr. James Hartness (Past-President of the American Society of Mechanical Engineers) said that this was the first opportunity he had had as a Member of the Institution to be present at one of its Meetings and he could not resist the temptation to bring a greeting from the Council of the American Society of Mechanical Engineers to the Council of the British Institution, and a greeting also from the members of the American Society to the members of the British Institution. He also further wished to greet them as an individual member. The greatest part of his work had been in connexion with the organization of the American Society, but the best part of his life and the most stimulating part was when he had no duties to perform which prevented him from mixing with his fellow members, and when he could enjoy the real life and benefits of the organization.

He would like to say a word on the Paper. He had been here for a month, as some of them might know, in connexion with aircraft standardization work, and during that time he had seen things which had caused him to come to some very definite conclusions with regard to women's work. If he could take back to America an impression of what he had seen in that direction, it would have a most stimulating effect in emphasizing to

America the things which it was necessary for her to carry out. He had been through the shops in this country, and he had seen men work and he had seen women work in an emergency. He had lived in the shops for many days, and he knew what the work was. He was convinced that women could not work that way for money. There was a something far higher than that; the women thought of the service they were rendering to England, and that must not be forgotten.

As to the number of men and women who left the shops during the year, as mentioned by the first speaker, he thought the position would be the same if the conditions were reversed. Let them assume that the women were accustomed to the shops, and that it was new to employ men there. In America they lost 50 per cent. of the new men who came in, and it was not to be expected that women, who were new to the work, would show any less percentage. He could not speak to the other points in the Paper, but he could not resist the temptation to give a greeting from the American Society to the British Institution as he was going back to America after a short stay in this country. He had been here some fifteen times before, and was a guest of the Institution in 1910. It had always been a pleasure to keep in touch with the Institution and to keep both bodies in touch with each other.

Mr. Richard W. Allen, C.B.E., said he had hoped to be able to prepare for comparison his experiences of two years' working as an employer of women. He would, however, like to tell Miss Monkhouse that the large number of women in his employment had his entire sympathy. The Paper had evidently been prepared by one who knew the subject thoroughly. It might be regarded as a Paper giving the years of experience of the difficulties that had to be encountered from day to day and week to week, and if the majority of employers in munition factories were asked to write a Paper on the employment of women, it would practically be word for word what Miss Monkhouse had said.

The Paper dealt with the subject from all points of view, and very rightly the employer was first mentioned, because success very

(Mr. Richard W. Allen, C.B.E.)
largely depended on the sympathy of the employer. Unless that existed, it could not be expected that sympathy would be extended by the management and foremen. He well remembered the earlier stages of the war when the question of the difficulties of obtaining men in munition works arose, coupled with the request of the Government departments to increase production and take on new production. His firm had a visit from a certain gentleman from the Ministry of Munitions who told them they would have to employ women. It was rather a knock-down blow at first and they did not see how it could be done, but loyally they agreed, and explained the position to the various foremen, who acted like sportsmen, and the firm had never looked back. His firm was engaged on complicated and difficult work for the Navy and also for the Air Service.

It had been remarked by previous speakers that women might be suitably and easily employed in repetition work to a very large extent, but experience had shown that if the employers exercised patience and taught the women properly, they could be equally well employed on general engineering work as in manufacturing. There was a very wide difference between engineering and manufacturing, but if they had patience with the women they would in the end be successful. A number of people were against the employment of women, but this feeling arose because they had not given them a proper chance.

Reference had been made to the difference in work of the women and apprentices. In the past, and in many cases, apprentices had been carefully taught, but the women had been brought into some factories with little or no tuition, consequently in some cases they had been rejected as being of little use, whereas if they were properly taught—and it was most important that they should be properly taught—he believed success would be obtained with women in engineering as in manufacturing work.

It might be interesting to give an idea of the work that women were engaged upon at the works with which he was connected. An example was a complicated aviation engine. His firm had prepared an exhibit for the Ministry of Munitions and it was on show

somewhere in London, and he advised a visit of every member to this exhibition to inspect the examples of what women could do after they had been trained. The work was performed most accurately and to very fine limits. They were also dealing with a variety of work for marine purposes including steam-engines, steam-turbines, oil-engines, etc., for the Admiralty, and they were training women to blade the turbines and to a considerable amount of various fitting work, with great success.

Reference had been made during the discussion to the question of turning women out as engineers, and although this could probably be achieved, he understood the Paper under discussion was confined to the employment of women in Munition Factories.

With regard to the three different classes of women mentioned in the Paper, he had only had experience of the first and the second, and he could entirely endorse what was said in the Paper with regard to women who had received a higher education. They certainly did come to the top very much quicker, and they were able to grasp the complicated nature of the work they had to deal with better than those who had received little or no education. Perhaps it was unwise to pat the girls on the back too frequently, but being a man who admired the way women had taken up this work, he could not help doing it. When they attended to their work diligently and turned out the work expeditiously, it warranted some little approval now and again; but it was desirable not to do this too often as they were inclined to be a little jealous. He was quite convinced, as was mentioned in the Paper, that one of the most important things was to make the girls happy while they were in one's employ. They should be given good dining halls and all the various conveniences, and in that way they could be made to realize that they had their employer's sympathy. Then he was certain the women would never fail an employer. In conclusion, he assured the Author that as far as his firm was concerned, they would do everything possible to help the girls forward.

Mr. William Rankine remarked that, although a great deal had been said of what women were doing in the factories, nothing

had been said of what they were doing in the training centres. Miss Monkhouse stated that probably the greatest success had been attained where the training school was in the works. That might be so, but many modern workshops had not the accommodation for establishing training centres, and as a result the women must mix up with factory conditions right away, and find opportunities for picking up what was necessary for them in the factory itself. In the training centre, however, away from the works, the women were first medically examined, and that was an essential feature, because it resulted in unfit women being rejected at once and not being disappointed after several weeks' work. If the girl was found medically fit, she was sent into the centre equipped with modern machinery and in charge of skilled men and trained teachers. An engineer might know his subject very well, but knowing a subject and imparting it to others was quite a different matter, and it was in this way that the girls often did not get so well trained in the shop as in the centre. Again, the advantage of training centres was that in dealing with women of higher education they were dealing with women who had been accustomed to a refined life; and if a girl went straight into the factory she was spoiled through the sudden changed conditions, although she might have the making of a good worker in her. In the training centre she became gradually accustomed to the different conditions in which she would have to work.

Again, if a girl went straight into the factory she might meet with some opposition, and probably it might also happen that the tool-setter under whom she had to work was not sympathetic, and that would upset her and spoil her chance of success. With the training centre it was different. The instructors were there for a definite purpose, to train the women and nothing more. When they were trained they went into the factory, and even though they might then meet with some opposition they were more confident and better able to hold their own. It was his duty to get into touch with employers and get to know the class of work for which they wanted women. He visited the factory, saw the work and examined the tools, and then proceeded to the training centre and

set up machines to train girls for this work. When they got to the factory the girls could generally set up their own tools, but it did not follow that those women should be expected to do another class of work.

When difficulties occurred in the shops, the girls always had the training centre to fall back upon. They often came back after working hours for help, and they worked there to get over these difficulties. They did not get paid for that, but did it for their own satisfaction and for the benefit of their employer. They also were taught to use various types of micrometers, verniers, depth gauges, etc., whereas in the factory there was usually no time for the foreman to trouble about teaching these things. In the centre there were facilities for teaching the uses of all these types of measuring instruments, and it was by this means that the girls went into the factories with a confidence which they did not possess when starting without any previous training.

Mr. William H. Allen (Vice-President) regarded the Meeting as epoch-making, because it was the first time that a lady had read a Paper before the Institution. He hoped it would not be the last. It was a Paper of particular quality, and he did not exactly agree with the President in what he said with regard to it. The ordinary run of Papers before the Institution were scientific, but this was the first Paper on Labour that had been presented to the Institution. He saw eye to eye in everything that Miss Monkhouse said, but when she said that everything depended on the sympathy of the foreman, he thought they must begin with the directors. The directors must have sympathy, and it must pass down from them.

A necessity beyond all others was a proper supervisor. It was necessary to get a woman, who should be a mother and a sister, to understand the girls and to put them in their proper place in the works. His son, Mr. Richard Allen, had omitted to mention that the firm employed 900 girls. Two years ago Mr. Lloyd George sent some one down to their works to ask how many they were employing. They thought they could then employ about fifty, and

(Mr. William H. Allen.)

little anticipated that in two years they would be employing nearly a thousand. It was from his experience of this number that he was able to say something of the advantage of having a good supervisor. In Bedford they had been fortunate enough to get Mrs. Lilly, who had chosen all these girls and placed them in their different positions, and they had not had to reject one single girl that she had engaged. There had been no trouble with the girls in any way; provided they were left alone, they did their work.

He could not quite understand from Mr. Wicksteed whether he was for or against the girls. He threw his arguments in right and left, but on the whole he thought he was for the girls. He was not with him, however, in thinking that this class of employment would cease for them after the war. Far from it, and he would give the reason. We were a sea-faring nation and our little island could never support itself, notwithstanding all that had been done by the Board of Agriculture and by our farmers who had made two blades of grass grow where one blade grew before. We should never be able completely to provide ourselves with food, and we should have to purchase our food with our industry. Before the war the Germans had most of the trade; the Mother Country was not large enough in industries to supply all the markets which could buy her goods. What was going to be done after the war? Surely they were not going to allow the Germans in again. Therefore they must consider the propriety of employing girls to help in industry in the future as they were doing at the present time.

Miss Monkhouse said that there were one million girls employed in munition factories, but Mr. Kellaway had stated that the number was a million and a half, and he ought to be right. He would therefore take that figure. They had come literally out of the streets and had not been away from their homes before. He suggested that girls should be properly apprenticed; why should they not be? It might be a great change in the status of England to do such a thing, but it would be to our enormous industrial advantage to have those one and a half million women helping in the engineering industry after the war. He hoped the trades

unions would not be offended with him for making such a suggestion. There would be work enough for everybody, both men and women, for years to come.

He only wished to refer to one other matter, and that was the remark in the last sentence of the Paper in which the Author urged that women should only be used as wealth producers in so far as that did not affect the healthy development of the race. That was most important. He hoped we should never go back to the pre-Shaftesbury days. They might all remember that the Earl of Shaftesbury, one of the greatest philanthropists who ever lived, spent the whole of his life in ameliorating the conditions of children and women, and upon his memorial in Westminster Abbey were inscribed the two words "Love" and "Serve." Think of the degradation of women that took place in Wales in the "Sixties." He had seen them in the mines himself, on their knees with chains between their legs, dragging the trams along after them. Surely we were not going back to anything like that?

In all works like his own where the work was plain and straightforward, the conditions were good; but in shipbuilding, for instance, it was a different thing altogether. German girls were working on shipbuilding at least a year before we started. Sir Lynden Macassey said he could not do without them as so many men had been taken away and girls had to be put on. It should be seen to, however, that women were not overworked so that they could not bear their womanhood. Unfortunately in the munitions book recently published there was a picture of a woman striker. It went to the heart to see this, but there was the woman all out of shape and form. What could she do with her womanhood when she was compelled to labour like that, just as they did in the pre-Shaftesbury days.

He invited Miss Monkhouse down to his works in order that she might find all the fault she could, because it was only by so doing that they could improve. She could then see the way they treated their girls, and when he was asked how he treated the girls his answer was, "Like my own daughters," He tried to do the best he could for them,

Mr. L. A. Legros said he had had a little experience in the employment of women in pre-war days on extremely accurate work, and therefore, apart from the knowledge he had gained at the Ministry of Munitions, some remarks from him on the Paper might be useful. In the first place the work which he endeavoured to get done by women with success was that of cutting the very accurate punches for producing printers' type. It was work which had to be done to the limit of a quarter of a thousandth of an inch over irregular and curved outlines. It was extremely difficult to reduce that work to a matter of dimensions and figures, and in order to get this work done by women he was obliged to train women himself. In fact he trained four, but to be quite honest only made a success with one; but that one was able to train others for several single operations, though not for the whole of the operations of either trade. It took him about two hours a day for six months, but he trained that woman to do three trades, the pay for which had been £5 10*s*., £4, and £3 10*s*. per week respectively, and therefore what might be called highly skilled trades. After the successful girl had been trained she could do any particular job in all three trades. In cutting these punches, whereas the best time by men before was 1 hour and his own time was 23 minutes, he had seen this girl cut one in 15 minutes. He admitted that the machine had been altered considerably from the style of machine which the men had worked with. It was made more fool-proof but not, as one of the speakers had said, "girl proof." The girl had to use her intelligence the whole time in order to avoid breaking the point of the tool, and she had to do her own sharpening and tool-setting. Then he came up against the difficulty that the men objected very strongly—this was in pre-war time, and so he was at liberty to talk about it—to women doing the work. The first thing they did was to supply soft cutters. The woman in charge showed him one of them and he told her to do nothing; but he hardened them himself, and next day the foreman came and complained that the women had been trying to harden their own cutters. Eventually that foreman found he was in the wrong place and he had to go. The fact that such work

had been done accurately and quickly by women had been a very great help to him afterwards in the Ministry work, because it had opened his eyes to what women could do. Women had been employed as surveyors on railways in Russia, and they could do accurate work in biological laboratories dissecting under the microscope; so long as they were not expected to lift weights of more than, say, 56 lb., or to exercise more strength than would be expected of a boy of 16 or 17 years of age, women were quite capable of holding their own for care, speed, and accuracy.

Coming to the work that women were put to in the fitting shops, he said there was a very great deal of bad training done by people who ought to know better. In many works women were put on to filing up pieces of plate. Instead of having the line marked out and being shown how to hold a file, it frequently happened that they were given pieces which were required in large numbers, and were supplied with a steel filing gauge. If a skilled man were to use a filing gauge he would put the work in the vice on the front side of the gauge, and only just touch the gauge with the file when he got down to the size. In quite nine works out of ten he found the foremen did not trouble about explaining this to the women; the only idea was to get the work done with the minimum of immediate trouble. The women were encouraged to use the hardened steel gauge on the near side of the work, with the result that the plate chattered and the file got worn down with rubbing on the hardened steel filing-gauge. He examined the reason for this because it occurred in so many cases, and the foremen said it was difficult to get true work if the women were allowed to put the job on the other side of the filing gauge, as they always filed uphill. He had had to tell the foremen in all these cases that the reason was because the vices were put at the same height as for men; they had not realized that the correct height for a vice was the height of the elbow, and for women this might mean two inches lower or more according to the standard of labour in the district.

As a sample of difficult work done by women, in the ordinary course, he mentioned an instance relating to the wire stays for

aeroplanes which had a small square formed on them in the process of manufacture just under the screwed head, by a planishing operation similar to that adopted for making a sewing-machine needle. To file $\frac{1}{8}$th inch square each way was not quite a beginner's job. A number of these wires were wanted urgently, and the lady in charge of the fitting shop said she would get them made by her girls who had been intensively trained. An American came round the works and said that, although he had seen many things done by girls in this country, he had never yet seen a girl who could file flat. They were able to show him in this shop three or four girls on the work he had mentioned, and measurement showed that their work was being done square and flat and to gauge for size.

With regard to the different classes of work suitable for women, for such rough and heavy work as driving overhead cranes a circus girl was the ideal sort of woman. For light and accurate work, girls who had been ladies' maids, or who had worked on delicate lace-work, turned out extremely good at small work and marking-off. If they could work on such flexible, stretchable material as textile fabric, they could do better at marking out on harder materials such as wood and steel.

Reference had been made by Mr. Wicksteed to the time taken on shells, but the times which he had mentioned were comparatively very slow compared with what he (Mr. Legros) had seen women do with special machinery. The average machining time of a 9·2-inch H.E. Mark IX shell, taken over a shift, including making base-adapter, pressing and turning copper band, and riveting and facing off base-adapter, was 170 minutes, of which 45 minutes were occupied in machining the base-adapter; that was less than half the best time taken in other works by men, and the shell-works that was making this record contained 95 per cent. of women. This remarkable result was, it was true, largely due to the machines, but also to the quality of the women labour employed, and to the efficiency of the management.

There was one point in the Paper which he would have put differently if he had been writing on the subject himself, and that

related to the classes of women capable of being employed on munition work. Miss Monkhouse had alluded to educated women in one class only. There were two classes of education; one was the ordinary school education on classical lines which could be paid for by the yard, so to speak, and the other was the manual and technical education which was so much harder to obtain. He could not have obtained success in the difficult work connected with printing type with girls of the mathematician type because the most important matter was to use the hands exactly in the right manner to produce the right effect; this could only be done by girls who had been trained as artists, sculptors, engravers, woodcarvers, etc.

There were women capable of becoming tool-makers and gauge-makers to be obtained by careful selection, but it was necessary to hunt them out of the schools of sculpture and other technical schools round the country. In this way girls had been obtained who were capable of making aircraft propellers, work which was now being done throughout by women, in certain works, and work which a short time ago was considered to be exclusively that of the highly-skilled pattern-maker.

The attainment of specialized skill was largely a question of intensive training, and this had been alluded to as being the right method for men as well as for women. In that connexion he might mention that at Panhard and Levassor's works in Paris there was a school attached to the works, run by old and disabled men, through which all the apprentices were passed; they had to spend so much time in the school in elementary work including fitting, turning, reading drawings, marking-off, pattern-making, etc., before they were allowed into the shops. When they had finished their apprenticeship they were definitely discharged, to acquire broader knowledge elsewhere for at least two years, in order that they should gain experience of other works and other methods. He had been told that the company had more than a sufficiency of their own apprentices returning to them after a few years' absence with added experience of other works.

Miss Monkhouse had alluded to the necessity for care in

selecting women. This applied even more strongly to the selection of the woman in charge of the welfare section. At one works the speaker had visited, unfavourable reports had been received. The lady superintendent was a highly educated woman in the academic sense, but not in the ways of the world. The works manager, who had engaged women previous to her appointment, had only one rule—" no laundry girl need apply " ; this had not been followed by the lady superintendent, and her choice had often proved inferior to the previous rough and ready standard of the works manager, with the result that the type of worker had not been so well maintained.

So far as his (Mr. Legros') experience went, the best teacher for higher grade women was a sympathetic man with the requisite manual skill, but the best teacher for the rank and file was a woman intensively trained for the particular branch of trade, and the best service and output was obtained from women under female supervision.

THE EFFICIENT UTILIZATION OF LABOUR IN ENGINEERING FACTORIES.

(With Special Reference to Women's Work.)

By Ben H. MORGAN, of London.

The immense demand upon the resources of the Engineering Industry for the production of munitions of war has necessitated many changes in our Industrial System, in order to ensure the most advantageous employment of labour and material. A great expansion of productive capacity had to be brought about, and while, thanks to the Navy, the supply of raw materials proved no insuperable difficulty, the provision of the necessary labour to utilize those materials was a question which could not be solved so readily. The number of highly skilled craftsmen in the country was limited, and as such men cannot be improvised, it was essential to utilize their abilities in the most efficient manner, and to draw upon the general labour resources of the country for all work which could be carried on without the lengthy and specialized training of the all-round tradesman. The only large reservoir of labour available was constituted of the women of the country, and thus force of circumstances brought about their general introduction into the Engineering industry.

The wide employment of women in engineering works and the engineering sense and capability that they have developed is undoubtedly one of the outstanding phenomena of the war. Not that there is anything new in the employment of women on engineering and allied work, for it is recorded, that half a century ago a firm in Birmingham employed, at one time, 2,000 women in its works. Generally speaking, however, their female labour was confined to rough and poorly-paid industries, such as the chain, nut and bolt, screw and rivet, and the small metal trades generally, though later women began to take a more intelligent part in the newer industries such as telephone and other instrument making, electrical work, cycles and motors.

Usually their more advanced work was confined to the operation of automatic and semi-automatic tools, such as capstans, presses, drills, screw and gear-cutting machines producing repetition work and requiring little more than manipulative dexterity, though there were a few women in isolated shops doing skilled work on the centre lathe and at the fitting bench: indeed, in the works of a prominent member of this Institution, women were employed on fitting work using micrometers and working to a half-thousandth of an inch, but this was an exceptional case.

Towards the end of 1914, however, when the country was faced with the necessity of enormously increasing its output of munitions after its skilled labour had been considerably depleted through the voluntary enlistment of large numbers of skilled men, a reconsideration of the conditions surrounding the possibility of a more general employment of women in engineering workshops had to be seriously considered. The first step in this direction was an attempt to employ them on shell production. It called forth a protest from the Trade Union concerned, but, after conference with the Employers' Federation, led to an agreement known as the "Crayford Agreement," under which female labour was admitted for the first time into shell making, but restricted to the operation of machines engaged on repetition work of an unskilled character.

It was soon seen, however, that this concession did not meet the needs of the situation, and in December 1914 another conference

was held between the employers and the unions at which the employers suggested the general relaxation of Trade Union rules and restrictions for the period of the war. No agreement resulted, and in February 1915 the Government appointed the "Committee on Production." The result of this Committee's recommendations was the "Shells and Fuses Agreement" by which women were allowed to do work which had been previously allotted only to skilled men.

Then questions of rates of pay, interpretation of clauses and other difficulties arose and threatened to become acute. To bring about the settlement of these, Mr. Lloyd George called a conference with thirty-three principal Trade Unions in March 1915 at the Treasury, which resulted in what is well known as "the Treasury Agreement." This Treasury Agreement may be said to be the first really constructive measure providing, subject to certain safeguards, for the suspension, during the war, of such Trade Union restrictions on munitions work, as might interfere with or hinder maximum output, and the "Munitions of War Act" gave the force of the law to this suspension as far as regarded Controlled Establishments.

Dealing with the subject of increasing production of munitions in June 1915, Mr. Lloyd George, then Minister of Munitions, said:—

"If all the skilled engineers in this country were turned on to produce what is required, if you brought back from the front every engineer who had been recruited, if you worked them to the utmost limits of human endurance, you have not got enough labour even then to produce all we are going to ask you to produce during the next few months. Therefore we must appeal to the patriotism of the unions of this country to relax these particular rules in order to eke out, as it were, the skill, to make it go as far as it possibly can go."

The first public explanation, however, of the changes needed to make up for the insufficiency of skilled labour was given by Mr. Lloyd George at Bristol in September 1915 in his famous "Mechanics' War" speech. When giving particulars of the bargain made with the Trade Unions, he said:—

"We want to turn the unskilled on to work which unskilled men and women can do just as well as the highly skilled, so as to reserve the highly skilled for work that nobody can do except those who have great experience, training and skill."

That was probably the genesis of what is commonly known as dilution. The retention of the principle so clearly enunciated in the foregoing statement would, the Author thinks all engineers will agree, be invaluable to British industry after the war, but where the Government have made pledges to organized labour, however disadvantageously they may operate in peace time, he knows that engineers will be the last to break the word they gave at a time of national stress. On the other hand, it is to be hoped that a time will come when the Unions will consider the whole question from the point of view of the national interest and industrial efficiency, as well as in the interests of the women who have given their labour so whole-heartedly throughout the war.

This speech was followed by the issue, by the Ministry of Munitions, of a letter of instruction to all Controlled Establishments in October 1915, in which firms were requested:—

"To take immediate practical steps in accordance with the conditions described above to give effect to these proposals in your establishment; that is to say, to replace skilled men wherever possible by less skilled labour, men or women, to use the skilled men so released in order to work night-shifts or work other machines in your establishment, and to make the surplus available for transfer elsewhere."

and also by the appointment, in the Ministry, of a Committee to deal with the dilution of skilled labour for the period of the war. Their scheme, which was adopted, contained the following three principal features:—

(1) "The principle of the scheme is that no skilled man should be employed on work which can be done by semi-skilled or unskilled male or female labour.

(2) The principle cannot be applied to all establishments in the same degree—for example, in a shop doing repetition work the scheme is generally applicable, whereas in a marine engineering or repairing works the scheme would be applicable only to a limited extent.

(3) It will be necessary to have a special survey of shops by fully qualified technical inspectors so far as possible, specially conversant with the employment of semi-skilled and female labour, who could advise the Ministry on the extent to which the dilution should take place and assist the employers in the process."

Many other considerations were involved in the report of the Committee, but the three points given represent substantially the scheme adopted, and continued up to the present time, for supplementing the deficiency of skilled mechanics.

Objections to the Scheme.—Before proceeding to analyse results, it may be opportune to note some of the difficulties met with in carrying out the scheme. First and foremost may be placed the objections of some of the rank and file of Trade Unionists to the infraction of their rules and customs, involved in a wider employment of women and unskilled male labour. The majority of the workers loyally adopted the spirit of the Agreement, but in nearly every shop there were to be found men who could not appreciate the national issues involved, but secretly or openly opposed the introduction of women workers. These objections were generally swept away by visits and explanation of technical officers from the Ministry, but in some cases they could not be overcome, and patched up local agreements had to be made, which led to disputes and restlessness, owing to inequalities in the application of the Committee's scheme in different parts of the country. Also the fear of making their own work unremunerative through an unfair adjustment of wages held many back from giving their co-operation. On the other hand, it may safely be said that the majority of the Trade Unionists gave the Ministry of Munitions their support, and it is due to their zeal in assisting in the training of the unskilled and in overcoming the very practical difficulties involved in closely sub-dividing operations to enable women to be employed, that so many are to-day engaged in engineering industries.

Probably the employment of women on munition work in

engineering shops was delayed as much by the conservatism of employers as by the objections of the Trade Unionists. The employer is proverbially cautious and difficult to move, and the convulsion of the war has not materially affected these characteristics. It was difficult to persuade the Trade Unionist that women could do certain classes of so-called skilled work because he did not always want to believe it, but the employer often met dilution proposals with a blank incredulity which was beyond the influence or reach of reason. All kinds of means had to be adopted to bring him to a realization of the real capacity of women workers.

The Author particularly remembers his early efforts to put women on to the building of 3½-ton motor-lorries while engaged firstly as a Dilution Officer and subsequently as Technical Adviser to the Labour Supply Department of the Ministry of Munitions. It was only after being treated as a humorist for a long time that he induced the management of the first works visited to train half-a-dozen women to perform certain operations. Going to the next works engaged on the same product he induced that firm to try a similar number of women on other operations. And so going from one works to another, always varying the operations, he got dilution under way. When the women in each shop had "made good" on particular operations, photographs were taken and results recorded, from which the Author was able to demonstrate that the bulk of the machining work in this particular branch of industry could be successfully done by women. After that progress was very rapid.

Another method of overcoming the prejudice against the employment of unskilled labour was to provide a few workers for particular operations from the training schools of the Ministry, in which some 40,000 persons have been trained. But perhaps the most effective antidotes to opposition were the distribution of the photographs referred to, the circulation of illustrated matter giving particulars of dilution examples and methods, the issue of process sheets setting out the actual work performed by women throughout the country in various products, the exhibition of

examples of women's work in the principal industrial centres, and addresses to workers illustrated by kinematograph films. These were some of the means used for showing both employers and workmen what women were capable of doing in the production of munitions.

Employers' Difficulties in introducing Women Labour.—But besides overcoming the objections of Trade Unionists, his own prejudices, and the difficulties of training unskilled labour, many special arrangements had to be made for the introduction of women into engineering works. Cloak room and lavatory accommodation had to be provided in conformity with the requirements of the Ministry of Munitions; attention had to be given to bad floors, and heating and ventilating arrangements had generally to be more favourable than in the case of men. Closer attention had also to be paid to the fencing of machinery, and special lifting and conveying appliances had sometimes to be provided. Then generally speaking shorter hours are necessary for women, and there are wages and piece-rate difficulties due to the greater subdivision of work, all of which involve expenditure of time and money in shop reorganization. When it is remembered that the majority of employers were faced with all these difficulties at a time when they were incredulous as to the capacity of women to produce a satisfactory output, it is easy to realize the task that confronted the Ministry of Munitions in the early stages of dilution.

On the other hand, unsatisfied demands for male labour compelled employers to give serious consideration to the employment of women on almost every branch of engineering work, from the heaviest labouring operations to tool-room work and setting-up, and many firms soon realized that good welfare conditions were, in the end, a profitable investment. Only those who, like the Author, have dealt with hundreds of firms on this matter, can realize what an important part deep-rooted patriotism, on the part of both employers and workers, played in effecting the introduction of female labour in engineering munition industries. The Author has in mind cases of firms who did not hesitate a moment in entering

whole-heartedly on dilution schemes in order to help to meet the national demand as expressed by the Ministry, and there were equally numerous cases of trade unionists who ran the gauntlet of local prejudice and ostracism to devote themselves whole-heartedly to the intensive training of women to fill the gaps in the labour requirements.

General Considerations regarding the Employment of Women.—There is no doubt that war experience with women in engineering works has entirely destroyed all preconceived ideas as to what constituted "skilled work." Previous to the outbreak of war, fully skilled men were regularly employed on work which can now be performed by women after a few weeks' training. It is not that the woman is a skilled worker, but has been put to do a job which is a sub-division of skilled work on which a fully skilled man was previously employed.

The assumption that is so often made that women become fully skilled workers in a few weeks is quite a false one. We can speed up the training of engineers by better teaching and apprenticing, but in the Author's opinion, neither a man nor a woman can become a fully skilled fitter or turner under a period of say four years. On the other hand, war conditions have enabled women to acquire a measure of skill in a far quicker time than men have ever previously acquired it. This is partly due to the patriotic desire of the women to assist in the war, and principally to intensive shop teaching under manufacturing conditions, as opposed to go-as-you-please academic training and drifting through works under pre-war apprenticeship conditions.

Women have generally been found to be accurate and conscientious workers. They acquire a high degree of accuracy quicker than men, through possessing a finer sense of touch. It has also been demonstrated that women are highly responsible workers, that is, that they can carry out with confidence finishing processes on large and costly work, and can manipulate high-speed and heavy machinery, in the operation of which there is a certain measure of risk, such as driving large cranes. Women are specially suitable for such skilled

and semi-skilled occupations as tracing, draughting, marking-off the lighter work of all kinds, and acetylene welding, while they are capable of acquiring a high degree of skill on sub-divisions of accurate tool-room work in turning, milling, grinding, and fitting operations.

Generally speaking, women may be said to have excelled in machining work rather than in fitting work. It is a peculiar fact that while women do not easily tire of machining operations with consistent repetition, they do stale on repetition fitting work, and quite a large proportion of them do not find the work sufficiently interesting to induce them to complete their initial training.

With regard to the employment of women on heavy engineering work there is a great deal of misapprehension. It is not generally understood that women can handle safely, in the course of machining and fitting operations, pieces weighing up to 60 lb., and can also manipulate almost as well as men, with the aid of lifting appliances, any weights over 80 lb. It is on work weighing between 60 lb. and 80 lb. where it becomes questionable whether women can be properly and economically employed. There is the cost of special lifting tackle and handling devices necessary for women that may be obviated in the case of men, and in instances where tackle has been provided for dealing with these weights, it has been found that women prefer not to go to the trouble of using such tackle and so overtax their strength by endeavouring to lift weights, which after a time generally results in injury to health.

In regard to output, women workers have increased enormously the records of output of all products of a repetition character which were current in munition firms previous to the war, but on non-repetition work it is doubtful whether they have, generally speaking, equalled the output of men.

As an example of increase of output obtained by women as compared with skilled men on repetition work, even of a heavy nature, the Author may cite the case of a factory making 9·2-inch shells. The practice in this factory was to bore the shell in three operations, and the total time taken for the complete boring by skilled men was 3·16 machine-hours. Women were substituted for

men on the boring lathes, and after one week's practice were able to do the work in an average time of 3·6 machine-hours. In less than three months they had reduced the average time to 1·25 hours, thus increasing the output to two and one half times its previous figure. Scores of similar instances might be quoted, but it is unnecessary, as facts like the above will have come under the notice of most of the members of this Institution.

It is an important point in the employment of women operatives in engineering work that they should be managed as far as practicable by women. If possible, women tool-setters and setters-up should be employed, also women charge-hands, sectional forewomen, and wherever possible women supervisors and shop managers.

Inequalities of Dilution.—The Author has already referred to the readiness shown by some firms to carry out dilution and the unwillingness of others. As dilution has progressed since June 1915 the disparity of effort has become more and more pronounced throughout the country. Cases are known where two firms, manufacturing exactly similar shells in the same town, employ, in one case 80 per cent. of women, and in the other no women at all. It is easy to realize the probability that such inequality has had a very disturbing effect on both workers and employers. That one firm should have agreed to the employment of female labour, and thereby involved itself in a large initial expenditure of time and money, while another, with a less appreciation of the country's needs, remained indifferent and immune from labour difficulties, doubtless did not tend to smooth the path of dilution. On the other hand, it was extremely difficult to bring about equality of dilution and equality of treatment under war conditions: for during the first year of dilution the employment of women on engineering work previously done by men was in the experimental stage, and no hard and fast rules could be laid down, owing to the uncertainty of output, the variety of the products, and the unequal conditions and equipment of the works.

Ministerial Action.—The first effort of the Ministry of Munitions took the form of letters of instruction urging firms to employ the

maximum number of women and unskilled ineligible men, and it was only natural that some firms should find it possible to comply with these instructions in a greater degree than others. Moreover it was found that despite the agreements made between the Ministry, the Employers' Federations, and the Trade Unions, some local shops refused to train and employ women, some groups of workers threatened to strike if their employment were insisted on, and in others strikes actually took place. Then the Ministry appointed a number of Dilution Officers to visit firms to explain to them what was practical in dilution, what assistance could be rendered by the Ministry's training schools, and generally to urge on firms the necessity of taking steps to increase the employment of unskilled labour. It was inevitable that this course of action (in his opinion the only practical course at the time) should lead to varying degrees of dilution in various shops and districts. The Ministry had at the outset to overcome prejudices on the part of both employers and workmen, arising not only from economic but political considerations, and the task that confronted them at times must have seemed almost insurmountable. The fact that the military and naval forces have been continuously supplied, and that some 950,000 women are engaged to-day on munitions products, turning out nearly one-third of the total output, gives some estimate of the success which has attended the Ministry's effort.

Two Kinds of Dilution Standards.—What seems to the Author the proper method of effecting dilution (now that the experience of the Ministry of Munitions has provided them with the necessary data) is to set up standards indicating the proportions of women, unskilled, semi-skilled, and skilled male labour, that should be employed on specified products, or where there are mixed products, on the work of the factory, segregated into classes of work. For some products such a standard has been set up by the Ministry; for instance, for all sizes of shell from 2·75 inches to 4·5 inches both inclusive, and this has been enforced by the insertion of the following clause in all contracts for the manufacture of these shells: –

"It is a condition of this contract that not later than 31st March 1917, at least 80 per cent. of the operatives employed in the execution of this contract shall be women. The expression 'operatives' shall include all those employed in unloading and loading, handling, machining, painting and varnishing, assembling, production and setting of tools, charge hands, viewers, and staff employed on repair and maintenance of machinery, and on inspection."

In all contracts for shell of sizes *over* 4·5 inches the following clause was added:—

"It shall be a condition of this contract that any directions of the Ministry of Munitions as to the number of skilled or semi-skilled male operatives shall be complied with."

The standards accepted by the National Shell Factory Committee for shell over 4·5 inches are as follows:—

15 inches, 12 inches, 9·2 inches and 8 inches, minimum 70 per cent. of women. 6 inches and 60 pdrs., minimum 80 per cent. of women.

It will be observed that while a definite standard is enforced by contract in the case of shell up to 4·5 inches, the standard for shells above that size was left to the discretion of the Department, the percentages agreed to being those at which the Department aimed in making its recommendations for dilution.

The effect of the dilution clause in contracts for shells up to 4·5 inches diameter inclusive has been very satisfactory, and some uniformity in labour conditions has now been effected throughout the country. Dilution at the discretion of the Ministry on shells above 4·5 inches diameter has not worked out so well, as there are still wide inequalities in the proportion of women to men employed For example, in one shell factory turning out 9·2-inch shells no women are employed, while in another making the same shells the proportion of women is 90 per cent. Such a wide disparity is, perhaps, not common, but it serves to illustrate the inequalities that have arisen, even in the production of such a simple product as a shell when minimum dilution ratios have not been enforced.

On all "straight line" repetition products such as shells, fuses, grenades, small arms, motor-cycles, small tools, etc., it has been

comparatively easy to establish definite ratios of skilled to unskilled male and female labour, but in dealing with such products as guns, standard motor lorries and the like, turned out in fewer numbers, and with shops having a mixed output, it has been found preferable to segregate the total labour into classes in order to arrive at the proportion of women to be employed.

The following Ministry of Munitions dilution standard on gun work is an example :—

Breech Mechanism.	Up to and including 8 inches.	Above 8 inches.
	Percentage of women.	Percentage of women.
Turning, boring, screwing, milling, gear-cutting, planing, shaping, slotting, grinding and all other machining operations	80	70
Gauging and viewing	80	80
Marking off, fitting and assembling . . .	50	40
Average for whole department, including proportion of tool-room, smiths' shop, beltman, millwrights, general labour, etc.	60	50

Note.—In calculating the above percentages all foremen, charge hands, supervisors and tool-setters are to be taken into account.

The percentages were fixed before much information was available. In some works higher percentages have been employed.

Making and Repairing Guns.—In connexion with the work of making and repairing guns up to 8-inch howitzers, it was considered that for the following operations the number of male should not collectively exceed the number of female operators :—

Rough turning.
Finish turning.
Rough boring.
Second boring.

Finish boring.
Rifling.
Planing.
Wire winding.

This standard was set up in such a way as to permit a considerable amount of flexibility in its adoption in different works. For instance, it enabled a firm preferring, owing to peculiarities of their machinery or other causes, to employ more than 50 per cent. of women on one of the operations and less upon another to keep within the standard in the aggregate.

Requirements of an ideal Dilution System.—In considering the question of dilution in its general aspect, it is not difficult at this period of the war, and with the accumulated experience of the Ministry of Munitions available, to lay down the main principles which should have governed action. The problem broadly may be stated thus:—The nation has decided upon a certain programme of munitions production as representing its minimum needs. To carry out this programme the number of skilled and semi-skilled men available was inadequate, and at any rate as far as the skilled men were concerned incapable of much expansion. There was, however, a considerable number of men, and a much larger number of women, whose energies could be diverted from their normal occupations to the production of munitions. Now the munitions programme to be carried out involved in its last analysis the provision of a certain number of labour-hours, and it was the object of dilution to provide these. The man-hours of skilled labour available had to be distributed as fairly as possible over the whole programme, and supplemented in an equally fair and general manner by unskilled labour which could be drawn from other occupations. It was, moreover, a primary necessity, and one that could never be lost sight of, that the limited supply of labour which was available should be utilized in the most efficient manner, and that waste of labour, by reason of inefficient machinery or bad management, should be stopped. The country could not afford such waste

Firms guilty of it should logically have been suppressed, and their equipment and labour transferred elsewhere, where it would be more productive. On the other hand, all firms producing their allotted output with a minimum of labour should have received encouragement to extend, a steady supply of orders, priority in their demands for material and labour, and assistance generally in the economical output of munitions.

Labour Efficiency Standard.—Now in order to detect inefficiency of manufacture and to conserve labour for productive purposes, it was essential that some standard of efficiency should be set up—in other words a definite number of labour-hours should have been allotted for the completion of a given contract, and steps have been taken to see that this allowance of labour was not exceeded; in other words manufacturers should have been rationed for labour in proportion to their output. This might have borne hardly upon firms with antiquated machinery and situated unfavourably for economical production, but in a national crisis consideration for such firms would be misplaced sentiment. For their waste is of the nation's wealth.

Dilution Standard.—In addition to the labour efficiency standard above described, a second standard should have been set up for all munition productions, namely, the percentage of female or unskilled labour to the total labour which should be employed on a given contract. This second standard, which may be called the dilution standard, would, by its enforcement, have brought about an equality of treatment between different firms, and spread the difficulties of training and employing unskilled labour fairly among contractors.

Dilution and Industrial Efficiency.—Under the ideal dilution scheme, therefore, firms would have been required so to organize and equip themselves as to require only the standard number of labour-hours to complete a contract for any given product; and, secondly, they would have been required to attain this result without a greater proportion of skilled labour than that permitted by the Dilution Standard. It cannot be gainsaid that the

determination of a standard of labour efficiency lies at the very root of economical production, and it would set for the first time in manufacturing, at any rate so far as Government orders are concerned, an attainable ideal of economical production and establish a criterion by which the respective merits of various firms could be judged. And, further than this, its adoption would involve implicitly a fairly close pre-determination of a contract price for a given product, which would allow a reasonable margin of profit to well-managed firms, and a fair rate of wages to the workers. The Government would have been able to make much better bargains than at present, and it is probable that the efficiency of manufacture and organization practically imposed upon contractors by the standards expected of them, would have left them, on the whole, more favourably placed than they now are. The Standard is the antithesis of the system of "time and line" contracts so much favoured at present by certain Government Departments, and would have abolished that system entirely except in very special cases, because the only justification for such contracts is lack of the data needed to estimate fair prices. The effect of the system of "time and line" is to sap the foundations of efficiency—as the more money a contractor can spend or waste on a given job, the greater is his profit.

Determination and Application of Standards.—It now remains to be considered how such standards can be practicably determined. Their enforcement, when determined, is not difficult under present conditions, because firms could be graded by an index number, jointly proportional to their percentage attainments of the two standards, and such index number would determine their position on all priority lists, whether for the placing of fresh contracts or the supplying of additional labour, material or equipment. Firms that either could not or would not so organize themselves as to meet the national requirements of the efficient utilization of labour would automatically find themselves gravitating towards the bottom of the list with the prospect of ultimate suspension, owing to necessary labour and materials being

diverted to their more efficient competitors. The question of the labour efficiency standards is merely the same problem, only on a larger scale, that confronts every Works Manager when framing an estimate or setting a piece-work price. He must make an approximate estimate of the man-hours necessary for the execution of a contract before putting in a tender. The Author hopes that in future contracts for munitions of war the Government will follow a similar course, collate the information available, frame standards, and enforce their application. It follows that such official estimates must be most carefully prepared and continually revised with the progress of the art of manufacturing. Where munition products or any other articles made in large quantities by various firms are concerned, the standard number of labour-hours required for a given output may be obtained from the actual records of the best firm—thus a practical attainable standard is set up which can be reached by anyone who will employ equally efficient methods of production. In the same way the largest measure of dilution attained in any industry might be accepted as a standard. The standards so fixed would not be open to serious criticism on the grounds of impracticability of attainment. They would, however, be only provisional, as it is clear that they would be considerably below those which might be set if the practices of a considerable number of firms were analysed, and the standards based on a composite selection, in the same way that the best bouquet would be made by bringing together the finest blossoms from a number of plants. It is by no means uncommon to find two firms taking approximately the same number of man-hours to make a given product, and yet to find so great a difference in the man-hours required for certain of the processes involved that if each firm would adopt the practice of the other whenever it was more efficient, the result would be materially to improve the efficiency of both firms. Similarly if women can be successfully trained to perform an operation in one firm, the employment of women might reasonably be enforced on the same operation in other firms, and thus an economy of skilled labour might be obtained which would be considerably greater than that reached by any particular firm.

Difficulties due to Variety of Products.—The attainment of a high manufacturing efficiency is very difficult when the energies and interests of a firm are spread over the production of different kinds of products, unless the output of each product is sufficient to justify a separate department, machinery and staff for its manufacture. It cannot be turned out as quickly, cheaply, or with so great a percentage of female labour as it would be under conditions of proper repetition manufacturing, and in the national interest, therefore, firms should be confined as far as possible to the manufacture of the minimum number of different articles. This applies particularly to the case of gauges, cutters, small tools, etc., which in the aggregate absorb a vast and needless amount of highly skilled labour when manufactured in small quantities by firms for their own use. In the interests of the conservation of skilled labour it would be well if all standard tools and gauges required for munition work were manufactured as repetition products in factories set apart for the purpose. In a word, the production of gauges and small tools of all description should be placed on the same basis as that of shells, fuses, or other direct munitions of war. A beginning in this direction has been made by the Ministry of Munitions who now have some gauge and tool factories in operation.

Standardization of Methods of Manufacture.—The Author has already explained how labour efficiency and dilution standards could be arrived at by merely adopting the actual figures of the attainments in each respect of the best firms. But in order to determine the highest practicable standard for any given product more information is required. It is necessary to analyse methods of manufacture down to the smallest details, and to consider every operation in turn both from the point of view of the labour hours involved and of the class of labour necessary to perform it. Such an analysis is no doubt made now in greater or less detail by every firm when planning methods of manufacture, but the Author holds strongly that for all munition products the Government should supply such information to contractors. It

would avoid all controversy about the possibility of attaining either the efficiency standard or the dilution standard required by the Government, because the possibility could be proved by actual performance. The Author does not, of course, advocate compulsory adoption of the standardized methods of manufacture where firms can produce equally good results by any other methods. But the standard established would assist them in planning work and complying with the Government's requirements as to the maxima of time and labour permissible for a given output. The first objection which will arise in the minds of critics is that all firms are not equally well equipped for production, and that it would therefore be unfair to insist upon the standards of time and labour being universally adhered to. In answer to this, the Author would say that his proposal would have the effect of preventing firms obtaining contracts which they are unable to carry out efficiently, and this would obviate the waste of material and labour which now exists. Furthermore, it would justify the application of a firm for such machine-tools as would enable it to carry out its contracts in the most efficient manner, and would, therefore, rapidly bring about the proper equipment of manufacturing firms for their special products. It would also have a good effect in the standardizing of the best machine-tools with a corresponding increase in the number available of the best types.

In conclusion, the Author would like to make a suggestion that this Institution should set up a Committee to study and report on the best methods, in each engineering industry, of introducing women into works, the best way of training discharged soldiers, with special reference to methods and appliances for employing maimed men, the upgrading of workers, the best methods of training male and female labour and cognate matters. Such a Committee could collect the experience of the members and make it available for the benefit of the whole, besides placing such invaluable records at the disposal of Government Departments dealing with labour dilution, reinforcement, and supply. This would not only be a valuable war work, but would have a lasting effect on British industry after the war, by helping to establish standards of output,

standard methods of sub-dividing work and the adoption of such plans as would give the best results in the various branches of engineering industry. Thus such a Committee could help the country to preserve for the benefit of British industry the dearly purchased experience gained in the struggle through which we are passing.

APPENDIX.

THE EMPLOYMENT OF WOMEN.

The following is a brief summary of work which was carried out wholly or partially by males before the war, and is divided under four headings:—(1) Construction; (2) War Work; (3) Operating; and (4) Miscellaneous Processes.

1.—CONSTRUCTION.

Aeroplanes.—The employment of women on covering, doping, painting and varnishing planes, ailerons, tail-planes, rudders, etc., has been general, and in many cases the work is done entirely by women.

The woodwork of aeroplane wings, ailerons, tail-planes, and many subsidiary details has been done throughout with the exception of machining, by women in many cases.

The work of assembling wings, ailerons, tail-planes and details, is done in many cases by women, but the erection of fuselages as sides, and the complete assembly of fuselages by women is rare, as also is the assembling of wings and the fitting of controls. The employment of women in higher grade work of this kind has been influenced by local conditions of management and by method, particularly where assembling is performed by a large number of highly specialized gangs, as is the case in a few of the larger works.

Airships, Balloons, etc.—The employment of women is partial, but comprises a very large percentage of the total workers, and their employment is frequent in this industry.

Ball-Bearings.—A large proportion of this work was done by women before the war, but the percentage has increased considerably throughout this industry.

In all the preceding cases the work is of such light character and so free from special conditions that no changes have been necessary, except the usual improvement in guards where machinery is used.

The period of training required varies from two to six weeks before the women workers can be considered efficient under preliminary conditions, with adequate supervision, and some assistance from skilled workers.

Boiler Making and Boiler Fittings. — This comprises the construction of boiler drums, from bending the plates to drilling and clamping in place; drilling tube-plates, bolting temporarily together, riveting, caulking and making fittings. In all these branches the introduction of women has been partial, but not frequent, except in the case of boiler fittings, which is the only class of this work considered suitable for women in normal times. The employment of women on semi-skilled and unskilled work has required training varying from a few days to four weeks.

Constructional Engineering. — This comprises the running of shearing, punching, bending and other machines, also temporarily bolting together and riveting up the bracing of girders, etc., by machine or portable hydraulic riveter. The same remarks apply as in the case of boiler making. In some cases the work of painting is done partially by women, but this is not yet general.

Electrical Engineering.—Whereas the machining and erecting of large dynamos and motors is now only partially effected by women in rare instances, and is not considered suitable for them in normal times, the machining and erecting of small dynamos and motors is of frequent occurrence. The same applies to the stamping out of laminations for armatures and transformers; forming,

winding, and taping coils; the making of paper and micanite tubes and moulded insulators; the making and erecting of switch gear of all kinds; the making of electrical instruments, meters, and of arc lamps. In all these the employment of women is frequent and partial, and the work is suitable for them in normal times without change in method of working.

Internal-Combustion Engines.—On the construction of the various parts of the engines for motor-cars, motor-lorries, and aircraft, as well as on gas- and oil-engine parts not too heavy to handle, the employment of women is partial and frequent, but on gas- and oil-engine parts too heavy to handle, involving increased labour and special lifting tackle, the employment of women is partial and rare, and the work cannot be considered as suitable for them in normal times.

Locomotive Engineering.—The machining of engine parts has been undertaken partially by women in some shops, and obviously much of the smaller work falls under conditions analogous to those of other allied engineering trades.

Machine-Tools.—Small and large machine-tools have both seen the partial introduction of women labour in very frequent cases. The work on small machine-tools is considered suitable for women, whereas that on large machine-tools is not, for the reason that increased labour and lifting tackle would be required.

Marine Engineering.—In the construction of ship hulls no application of woman labour has been made, nor is it considered practicable owing to the heavy character of the work and the amount of climbing involved; but on the construction of engines and turbines, for the work of painting, scaling, etc., and for the electrical wiring of ships partial application has been made in not very frequent cases.

Motor-Lorries, Cars, and Motor-Cycles.—The engines and

transmission gear as well as other components are frequently made partially by women. The period of training varies from one to six weeks, and requires ability to work to gauge. Work on the chassis of cars and lorries is of rarer occurrence and is not considered suitable for women in normal times; the period of training required is from six to ten weeks, but the work is generally considered rather too heavy. On magnetos, carburettors, and speedometers the work is in some cases now more than half done by women, and is eminently suitable for them, requiring no change of method or machinery but considerable accuracy and care. The training period varies from three to ten weeks.

The body-work of motor-lorries, motor-cars, as well as upholstering and trimming are not considered suitable for women, nor have they been employed on these for the reasons that the carpentering on lorry bodies is considered too heavy, and the coach-making thought to require so much skill that in general it would not pay to employ women on this class of work. The objection to women upholsterers and trainers is peculiar, as they have done this work successfully on railway coaches.

Railway Carriages and Wagons.—The whole of the work on underframes, wheels, axles, truck bodies, railway carriage building, railway carriage upholstering, painting, glazing, etc., has not afforded scope for the introduction of women at present. It is a fact that in pre-war times the trimming and upholstering of railway carriages was done by women in certain cases. The objections now raised are that the work is too heavy in the earlier classes and rather heavy in the latter.

Steam-Engineering and Pumps.—The machining and fitting of light parts has been done partially by women in rare cases. For machine and bench work a training of from one week to six months is required.

Precision Work and Tool-Room Work.—This involves the making of engineers' gauges of all kinds, including those for screw-threads,

all cutting tools such as taps, dies, cutters, twist-drills, reamers, and all jig details and parts. The partial adoption of woman labour in all these classes is frequent, and the work is considered suitable for women with training in the use of measuring instruments of from three to eight weeks.

The making of measuring and drawing instruments involves rather higher skill, and the application of woman labour to such work is extremely rare at present.

(2) WAR WORK.

Guns and Gun Components. — This comprises jackets, tubes, etc., breech mechanism, gun-sights and gun-carriages. The employment of women is partial and rare on all except on the breech mechanism on which it is frequent. Both this and gun-sights are considered work of a class suitable for women. The training period required varies from one to six months, and owing to the skill involved, women require increased experience for such work as gun-sights.

Small Arms. — Partial work by women is general. It is considered suitable for them, and the training period varies from six to twelve weeks.

Rifles, Lewis Guns, and other Machine Gun Work.—Though highly accurate are well inside the ability of women.

Shells and Components.—The forging of shells and adapters as well as cleaning, painting, and stamping of shells over 4 inches diameter is only done in rare instances partially by women, and is not considered suitable work for women in normal times. All of these are unskilled operations requiring little training, but the nature of the work is too arduous and too heavy for women.

The operations on machining shells over 4 inches, and of general labouring in shell shops are now generally performed partially by women, but the work is not considered suitable for women in normal times because of the increased amount of lifting tackle

required and the heavy handling involved, except where the shops are specially laid out for this product.

The machining of shells up to and including 4-inches of base plates and adapters, of nose bushes, gaines, and fuses, the gauging and viewing of shells and components, and the cleaning, painting and stamping of shells up to and including 4 inches are partially performed as a general rule by women, and are considered of a character suitable for women, as these operations involve no change in methods of this semi-skilled work, which requires a training of from one to three weeks only.

(3) Operating Work, Non-Constructional.

Crane Driving.—The introduction of women into this branch has been partial but frequent. It is considered suitable work for them, but the cranes, when of the overhead type, require, in many instances, better facilities for access. For such rough and heavy work it is, of course, necessary that the women workers should be suitably clothed; this applies also to work on large aeroplanes, and on aeroplane erection, as well as on boiler-making and constructional engineering.

Power Plant and Electric Station Work.—The work of operating boilers, gas-producers, etc., is not performed by women except in very rare cases, and is not considered suitable for women in normal times. General labouring in power stations is at present done in rare instances by women, but it is also not considered suitable, on account of the climbing and risk involved.

Operating steam-engines, gas-engines, dynamos and electrical switch-gear is partially done by women in some instances. The training involves knowledge of the principles and construction of the machinery, and in the case of switch attendants an elementary electrical knowledge. The period of training varies from one or two weeks to six months. One objection to the employment of women on this class of work is the shift system, universal in power stations, which involves a change of shift at midnight, a time which would generally prove unsuitable for women.

(4) Miscellaneous Processes.

Acetylene and Electric Welding.—The partial employment of women is general on this class of work, and it is considered suitable for them in normal times without change of method. The requisites are care and experience and a training period of from one to ten weeks.

Lacquering, Bronzing, Enamelling, Painting and Stencilling.—The partial employment of women is general, and it is considered suitable for them in normal times; care and a short training of from one to three weeks are all that is required.

Blue Printing and Tracing.—The partial employment of women is general, and it is considered suitable for normal times; care and neatness are the chief requisites with a training period of from one week upwards.

Draughtsman (Junior).—The employment of women is here more rare, but it is work considered suitable. Knowledge of machine-shop work is necessary, and the training involves that for blue printing and tracing as well as additional experience in drawing and projection. The need for shop experience is great, but the difficulty attendant on the employment of women in this branch is diminishing owing to the increase in the number of works in which women have been employed in working, from actual drawings, and not on mere repetition.

Tool-Setting.—The partial employment of women is frequent, and the work is suitable for normal times. The requisites are either considerable experience as an operator, culminating in setting own tools, or a course of four weeks and upwards of specialized setting on machines of the same class. The tool-setter who can set up for any kind of work is highly skilled, but when the question is reduced to a particular class of machine, or of machine work, the field is limited, and the skill is reduced to more specialized limits.

Viewing and Gauging.—The partial employment of women is frequent, and it is work that is considered suitable for women in normal times, in fact, women have been employed in pre-war time in many branches of industry in viewing operations. The limitations occur when parts are too heavy for them to handle, or when experience of materials, such as timber, is vital. The training involves accuracy and intelligence as well as ability to understand drawings, and instruction in the use of measuring appliances for a period of from one to six weeks. In some instances, experience of specialized character is necessary to determine whether the finished workmanship, or material, or other variables are satisfactory.

Wire-Drawing and Winding.—These operations are not performed at present to any great extent by women, though they are considered suitable for them in normal times. The requisites are knowledge of the process, and a short training of one or two weeks; the only limitations are those imposed by want of physical strength.

Making and Breaking of Test-Pieces.—The partial employment of women on making and breaking test-pieces is not very common, but it is work considered suitable for them in normal times; the requisites are ability to read drawings and measuring instruments, combined with a knowledge of accurate turning on the centre lathe, or precision grinding, together with a training of three to six weeks in the operation of a testing machine. The breaking of test-pieces is in many cases a fairly simple operation when the yield-point of the metal is well marked, but in the case of some steels and some non-ferrous metals, greater experience in testing is necessary, as much may depend upon the observation of the yield-point of the individual material under test. All the auxiliary work of measuring the test-pieces before and after fracture as well as the calculations involved in the determination of the elastic and ultimate tensile strength, percentage of elongation and reduction of area, are well within the capacity of women who can machine the test-pieces, use the slide-rule and work the testing machine.

Discussion in London, on Friday, 3rd May, 1918.

SIR HERBERT AUSTIN, K.B.E., said he entirely agreed with the general remarks made both in Miss Monkhouse's Paper and in that of Mr. Morgan with regard to the employment of women. He spoke from experience as an employer of something like 6,000 women and 14,000 men. Some of the women were engaged on shells, and others on the very finest operations in connexion with grinding and machine work, which previously had been considered entirely a man's job. Holding those views, it was rather difficult for him to outline any criticism of the Papers, because he did not think that, at any rate, Miss Monkhouse's Paper admitted of much criticism. The facts enumerated in it were quite definite and he entirely agreed with them. On the other hand, he thought that possibly many employers had been blamed for diffidence in the employment of women when really the reasons were not all apparent. It had been said that they were afraid of employing women because they did not think they could do the work. Now there were other reasons, and he would like to mention one or two of them.

In the first place, he felt confident that many employers believed that if they instituted dilution, put in a lot of women labour, and went to a great deal of expense and trouble, their methods would not be followed by other manufacturers who would not be compelled by the Ministry of Munitions to put in the same proportion of women. And when an employer who had put in a great amount of dilution, and was suffering under the difficulties naturally contingent upon the employment of unskilled labour, and making changes in his works and fittings—when such an employer saw other firms with no dilution whatever, it naturally made him feel disinclined to follow the wishes of the Ministry in putting in dilution from time to time. He knew of some factories in his immediate neighbourhood which had carried out no dilution whatever. That partly arose, he believed, from the fact that they were doing Admiralty contracts, in which they had preference, and

the unfortunate firms who were doing munition contracts had not the same amount of protection. Then again, the Ministry of Munitions was made up of quite a large number of departments, and it was not the dilution officers who came round to blame one for not having turned the work out quickly and properly, and made a good job of it; but it was the other departments, who had no sympathy whatever with dilution. Thus employers were faced with very considerable difficulties, and after they had had a year or two of that sort of treatment, they naturally did not like meeting the requests of the dilution officers so freely as they otherwise might. He himself had really now arrived at a condition where he did not like to see the dilution officer. He had at the present moment two in the factory who had been there nearly a week, and he had told them when they arrived that he could not give them any further assistance; and he believed that other firms in the country now had arrived at that position. They had done their fair share, and matters had arrived at a position where, as Mr. Morgan pointed out in his Paper, it ought to be made compulsory for others to do it, and then there would be no discussion about women being able to do men's work. Everybody admitted that; there was no difficulty about it at all.

Then, again, there was another fear which had not been touched upon in either of the Papers, namely, as to whether women would be available after the war, and whether the time taken in teaching women and making provision for them in the shops was going to be worth the expense and trouble. Before the war he had set his face against any women being employed in his factory—he did not think it was necessary—and he was frankly looking forward to the employment of men in the factory after the war, and to its not being necessary to employ women. That was not because women had not done their fair share—they had done more than their fair share. When the war was over and the time came for summing up the work done by women both in skilled and unskilled labour, he had no doubt that they would show very well indeed. But he was not looking forward to women doing a man's job after the war. He thought it was a man's duty to do the hard work in an

(Sir Herbert Austin, K.B.E.)
engineer's shop, and that there was other work for a woman to do for which she was more suited. The advocates of women's labour seemed in nearly every instance to be consumed with the fear as to whether they would be allowed to work, or whether facilities would be given to them. He was most concerned with the question whether they would be willing to work themselves—whether they would not find other temptations to push their energies in other spheres, and would not want to carry on the work that they had been doing so well in engineering factories. He thought Mr. Morgan possibly did not know of all the difficulties with which some manufacturers had to contend, and perhaps he had not considered, on the question of efficiency and of allowance for output, the question of changes in design that had to be made, particularly in the direction of aeroplane and aeroplane-engine contracts. He did not quite know how Mr. Morgan would suggest that figures should be laid down as to what the output per man-hour should be, but he would be very much interested to know what Mr. Morgan had to say on that matter, because really he did not think it had any relation to-day with aeroplane-engine work compared with the difficulties that one had to meet with in the frequent changes of design made necessary by the continual demand for improvement.

Sir GUILFORD L. MOLESWORTH, K.C.I.E., said he could not in any way criticize the admirable Paper by Miss Monkhouse which had been laid before them. It abounded in cogent and logical reasons, it was replete with good, sound, practical, common sense. The franchise had been granted to women, and they had proved their ability to perform work with efficiency which previously had been considered to be exclusively within the domain of men. Women's work had come to stay. It would not end with the war. It was probable that many now working at munitions would remain to work, if not in munitions, yet in work which would be urgently required to recover our lost industries, and to repair the waste that had been made during the present war. But care must be taken that they did not fall into those pitfalls which had ruined Trade

Unions, which had demoralized and enslaved the British workman, which had caused unemployment and pauperism, and which had enabled the Germans to capture our trade and industries.

In his younger days he had passed an apprenticeship as millwright and engine fitter in Fairbairn's large engineering works at Manchester, and after the outbreak of the war he had volunteered to work as a skilled mechanic in making shells at the works of Messrs. Vickers, at Crayford, without pay. His offer had been accepted, but he might say that the manager had informed him that his services would be more valuable in office work than in actual manual labour. He had worked with them for nearly five months, but was then obliged by medical orders to relinquish it. During that time he was convinced from personal observation and from conversation with the workpeople that the output of munitions was most seriously and wantonly restricted. The greatest danger that menaced the future of women-workers lay in their enslavement by Trade Unions. He did not think that women workers realized the dangers that existed from that. Women workers of the future must avoid any form of trade unionism of that kind. No doubt some organization must be formed to protect their interests, but it must be one that left the worker free. It must be consultative and advisory rather than administrative. It must not meddle with politics, and it must not join with any Party. Miss Monkhouse would do right good work if she would organize and be President of such an organization, the constitution of which should be entirely on the lines which she had so ably submitted.

Miss A. M. Anderson (H.M. Principal Lady Inspector of Factories) said that Mr. Morgan's Paper needed a great deal of study on her part to enable her to contribute anything at all to the discussion. Her point of view was that she approached the whole subject from the opposite end. Mr. Morgan's chief interest was in the placing of Government contracts where the best conditions obtained for the most successful application of material and labour. Her interest was much more in the direction indicated in parts of

(Miss A. M. Anderson.)

Miss Monkhouse's Paper—that of placing contracts, if she had any share in the placing of contracts—rather where the best conditions obtained for safeguarding the life, and health, and limbs of the workers. Mr. Morgan's interest was quality and quantity of the product of labour; hers was the quality of the life of labour. She had no doubt whatever that rationally organized the two aims would meet in industry, and would meet to the enormous advantage of the nation and of the worker. There could be no hope of the highest efficiency in the product of labour without the fullest possible regard for the life and safety and welfare of the worker. She had seen very much more of the problem of dilution of labour, the application of increased employment of women's labour in non-munition industries than in engineering industries. There had been there a most marvellous development, which could be seen in the pamphlets published by the Home Office and by the Board of Trade, on substitution of women in a large number of non-munition industries. In those industries there had not been the application of that extraordinary, specialized training that had been organized for engineering industries. It was not yet known what could be done in all those directions when they had complete development of training.

She rejoiced greatly at the extension of women's work, and the fullest possible opportunities for application of their special gifts where they could most aid industry. But she was inclined to agree with what Sir Herbert Austin had said with regard to not bringing women on too large a scale into special men's work. Where women could really assist by their special gifts and special training, to the real advantage of the nation and to the development of their own powers, it would be a very great gain; but she did not want to see them permanently brought in in very large numbers, having their own much higher callings, to fulfil any massive, heavy labour that was peculiarly suited to men.

Mr. C. Faraday Proctor said he had had about thirty-seven years' experience in the employment of women. In 1881 he went to Paris to start the first incandescent electric lamp factory, and

the work being of a very delicate nature they naturally employed women. In 1883 he returned to England to install some new plant and instruct girls how to work it. In 1884 he went to Lille, to restart a factory which had been burnt down; girls were also employed there, and in 1888 he went back to Paris to start a very large incandescent electric lamp factory. Up to that date glass-blowing was very largely in the hands of Germans, who very seriously limited the output and refused to allow the teaching of boys. Again he turned to women labour, and very soon the women and girls were turning out the same number of lamps as the men were making, and went on until their output was double; and when his new seal—the internal glass stem—was introduced, their output became four times the output of the men. Their success was not purely a question of their being more able—although neatness was a very special characteristic of the French girl, and an essential to good glass work—but because they put their best efforts into their work and did not attempt seriously to restrict output. In that factory he had also found—he was still speaking of the new Paris factory—that the education of the women was so good that he could employ the ordinary workhand for clerical work, and the whole of the factory books were kept by girls, and stood the test of most critical auditors, and were certainly the neatest work he had seen.

He was so proud of their work that he had brought a few sheets with him to show anybody who was interested. But the special value of the point was this, that when he was in the North of England and had started another factory there, he had got a young man who believed that he was about as fine a clerical man as existed, but he did not do his work anything like as neatly as the Paris girls did. However, he was the right type of man, and made up his mind he could and would do as good work, and soon made such an improvement in the book-keeping and system of accounts that their London directors adopted it for their London works also. That man was now manager of a large business abroad.

He (Mr. Proctor) had always advocated women working and generally joining in business matters, and he believed that a woman

(Mr. C. Faraday Proctor.)

could do almost any work which a man could do; indeed women were very much what men made them, and men were what women made them; if the lazy and drunkard could be boycotted, they would die out, and if men were satisfied with dolls or playthings for their wives, and would leave the hard working intelligent spinsters to one side, the race was bound to deteriorate. There must be good intelligent women for the bringing up of the children and the future generation; if they were proud of their ancestors surely they were unworthy of them if they did not see that their successors were at least equally worthy.

He believed in the laws of cross inheritance, that is to say, a girl inherited more largely from her father, whereas a boy inherited more largely from his mother; were this not so, the difference between the sexes would steadily increase. Some thirty years ago Sarah Grand in her memorable lecture on "Mere Man," pointed out that man could not hope to raise his general status if he denied to women a higher education. Women had all the early training of the child, and very largely influenced the young man, and in later life often influenced even their greatest statesmen.

The Meeting might feel that he was travelling rather far away from the subject, but was a Paper on "The Employment of Women in Munition Factories" the sort of Paper the Members of the Institution of Mechanical Engineers were accustomed to? or expected? Was it the type of Paper that should be read at their Meetings? He said most emphatically, "Yes." Their Institutions were getting so exclusive or specializing to such an extent that many of the matters vital to the national welfare were neglected, because they were just outside of the particular corner in which that Institution was interested.

The politicians talked about setting up machinery for each new organization. Why "machinery"? He believed because it symbolized perfect organization; and although among the great nations they were probably the most incapable organizers as far as home-work went, when they were driven to it—the colonies for example—they were not found wanting. No man ever spoke more truly than did King George when he called on them to "wake up." They were

once the Engineers of the World, and possibly they still held the records for some of the great engineering feats of the World—the Forth Bridge and the steam-turbine were British. They might hold the record for aeroplanes, but only because they were compelled to do it, and motor-cars! Consider the Ford car made by workmen receiving almost double the pay of an Englishman, made hundreds of miles away, and sold here at half the price of our cars—surely a fine example of organization; and yet he was convinced that a small light motor-car could be made even by English labour for half that price. He had been through many of the small-arms factories in Belgium, Verviers, and Liége, including the Herstal works of the Fabrique Nationale, and his impression was very strong that our want of success was largely owing to our slovenly methods of organization. Their employers and teachers asked for higher education and technically-trained men, but would neither pay them, use them, nor give attention to their advice.

He was convinced that the outstanding difference was that the foreigner—French, Belgian, possibly German and the American, enjoyed their work; the French and Belgian enjoyed it more than their play, the American as much as his play, but the Englishman in many cases detested it because it was work. In France, Belgium, and America, probably two-thirds, if not three-quarters of the population worked, and it was considered correct and necessary to work, whereas in England less than half the population were at *regular* work. He did not in anyway wish to depreciate the never ending labour of the women at home, but he was trying to see how the employment of women at regular organized factory work would influence the nation, themselves, and the men. A nation's wealth consisted of labour and raw material, either in the stored-up forms of capital, or worked-up material in one kind or another, or in the form of active labour, that is, the power to convert the capital or materials into some desirable form; it was thus necessary that labour should be skilled, and as abundant as possible.

The past condition of women must have been detestable to every high-spirited person, her prospect in life was very much a wait-and-see existence, she was a veritable derelict almost compelled to

(Mr. C. Faraday Proctor.)

accept any port for shelter. Could there be any question as to whether women should do every sort of work they were capable of doing fairly well so that they could support themselves, and from what point of view could a man object? Was he afraid of competition? If so, then it was the very thing he needed; if most of the girls he met had learnt to do regular work, surely they were more to be admired than the easy-going frivolous girl. If his wife had learnt to earn her living she would value money more, and should an accident deprive him of the power of work she could provide for herself.

In the business of electric-lamp making, women could and did make every part of the lamp except the actual blowing of the bulb, but even that he considered was women's work and should be done by them, but at present the law was against their doing this class of work. Almost all the work in connexion with small electric motors and small porcelain fittings, and very many other classes of light work, women were specially adapted for, and in all cases where accuracy and neatness were of value they excelled. Girls, he found, certainly excelled in doing delicate repetition work where many hundreds of an article were wanted per day per hand; they seemed to be able to do it in a semi-conscious way, and the monotony did not trouble them; indeed any variation they seemed to regard as a trouble, whereas a boy could not be kept at the work. He felt that some girls regarded the work as marking time until they got a home of their own, and that their mind was scarcely occupied with the work; such an attitude would never lead to efficiency.

He had often been asked why women were not paid as much as men. There was a very good reason; if a boy and girl started work together, the boy would at first get ahead, then the girl would pass him, and at eighteen years old be much his superior, but between twenty to thirty she was a very problematical employee from the master's point of view; any day she might come and say she was going to be married, and there was no help for it. All her training was lost from the master's point of view; on the other hand if a man were going to be married, the master knew that he had got him, and that he would stick all the harder at his work.

There were two other serious problems to be considered in this connexion; some people contended that if women and men were all working at their hardest it must result in overproduction, but he did not think it was a correct view; there might be overproduction of one or more specific articles, but that was owing to want of organization. Perfect organization and unlimited production—which was humanly impossible — would only mean that every individual would possess everything that his imagination desired.

The second point was that if women were earning approximately as much as men, what was going to happen when they got married. At first there would be the economy of one dwelling, but if the woman gave up her employment their income would be halved; if she continued at work and the children were put out "en nourrice," that is, sent out to the country to be cared for by paid strangers under the supervision of a Government paid doctor (as was frequently done in France), although quite practical, and leaving the parents at liberty to give all their attention to their work, she was giving up one of the most important duties of motherhood, and it did not appeal to him (Mr. Proctor) as the right thing. Yet they could not expect the employer to double the salary of a man because his wife was going home to look after her children, although they were the future representatives of the nation; or must the country provide a sum sufficient for their support and training, and at the same time see that the money was being used economically, and for the benefit of the wife and children? or were the population going to be persuaded, or compelled, to save enough money to provide for the proper maintenance of children if they had them? It was a big and complicated problem, but just one of those points that were apt to be left as not belonging to the scope of the Institution of Mechanical Engineers, and yet was of as vital importance as engineering itself, and should not be separated from the subject of "The Employment of Women in Munition Factories," for to quote Miss Monkhouse—"On her largely depends the life and happiness of the Nation."

Mr. JOHN ABBOTT said he entirely agreed with Miss Monkhouse and Mr. Morgan. It seemed as though they were all agreed that women were capable of doing several jobs which Mr. Morgan referred to as "sub-division jobs" of skilled labour. He himself had had twelve years' experience of female labour, and could hardly agree with one remark made at the last Meeting—that women were less conscientious than men. Age for age he had found them more conscientious. Possibly the explanation of this was that in many factories more care had been taken in the choice and training of women than of men. It might be thought he was now rather making an excuse for his own sex, but that was his experience. These factories employed ladies whose duty it was to go round making suggestions for the betterment of the conditions of the girls, whereas often the boys received much less attention. It was absolutely essential, in his opinion, to have women supervisors immediately over girls, because a man was at a severe disadvantage in such a capacity. A girl in a factory would probably weep immediately she saw she was getting the worst of an argument. He thought all men knew the hopelessness of reasoning further when that happened, whereas a woman supervisor could carry her point under her employer's instructions, giving the woman her answer back—not necessarily weeping, but still using equally forcible arguments.

He thought it essential that there should be a really reliable welfare-worker. The welfare-worker was frequently a thorn in the side of a works manager, but yet, after all, it kept him straight and enabled him to concentrate his attention on the things that mattered with regard to engineering problems, and it relieved him of a lot of detail. He thought the Government ought to do—as, in fact, they were doing—a great deal in the training of welfare-workers, but it was a position of such responsibility that they should be very carefully chosen. They must have the full confidence of the employer and of the employee. Without that the whole scheme would be a failure. He felt that female labour was not for the period of the war only. Work was a law of Nature, and providing racial health was protected by law, it seemed as though the

employment of women should be a question between the employers, the employees, and the men whose competitors they were. He thought that the women in fair competition would retain their jobs. If employers got a job done at a cheaper rate by women, he thought there would be cause for trouble, but surely none of them would object to paying the same amount to the woman worker if the product was equally satisfactory.

Major S. Heckstall Smith said that there was one point on the subject of dilution which seemed rather an important one, namely, that the very earliest stages of dilution could be reached, he thought, on the designer's table. That point had been very much overlooked in many munition works—that when dilution had to be studied, the designer could do a great deal towards it. If the Ministry of Munitions had brought that out strongly some time ago, it would have done much good, but even now he did not think it was too late.

He would like to disagree with Sir Herbert Austin on one point. He had been working for many years now on aeroplane building, and had employed women before the war on the mechanical parts of that work, and he hoped to employ them after the war. He thought one of the most important things—which had not been mentioned in either of the Papers—in regard to the employment of women (he was speaking now of after the war, because at present, of course, it was an absolute necessity) was the fact that the prosperity of every country largely depended on what he might call the family wealth. The better education, the better health, the better housing of the workers depended on the amount of money which a family could earn, and the amount of money which a family could earn depended on the maximum number of people in that family gaining employment. And therefore, living in rather a remote place where it was difficult to get a large number of mechanics, but where they wanted a large number of employees, and where house rent was expensive, they had found it absolutely indispensable to employ women before the war in order that people might have enough money to live in the neighbourhood, which they

(Major S. Heckstall Smith.)
could not have unless the whole family were employed. He therefore thought it was a most essential thing that the employment of women, especially young women, should be considered most seriously, as it was now being considered—that it should continue to be considered seriously after the war, for the general benefit of the welfare and wealth of the country.

Sir HERBERT AUSTIN hoped that he was not out of order, but he understood this discussion was entirely with regard to the employment of women in engineering factories and not in other factories. His remarks with regard to his not having employed women before the war were entirely confined to his own engineering factory.

Mr. WILLIAM REAVELL (Member of Council) said there was one paragraph in Mr. Morgan's Paper with regard to which he would like to ask him a question. He referred to the passage wherein Mr. Morgan expressed the opinion, from his experience, that women had excelled more in machining work than in fitting work. The question he wished to ask—and no doubt it was in the minds of many employers who, like himself, had used women's labour with so much satisfaction and success—was this: Did Mr. Morgan mean by fitting work, the fitting up of parts which would go together without requiring the use of a file or a reamer, as, for example, in fuse fitting; or did he mean skilled fitting work, where it was necessary, after the work came from the tool, to have a fine file or a scraper applied to the work before the parts were fitted together? His own experience was that in fuse-making, for example, where the fitting consisted in fitting together the fuses as the parts came from the tools, and where no skilled fitting, in the sense of using a scraper or a file, was required, woman's work in fitting in that sense was much superior to that of men. Their deftness of touch and their neatness of fingers enabled them, especially when piecework, or, as he preferred it, bonus work, was employed, to far exceed the speed with which men, or boys well in their teens, would do the same kind of fitting together of parts.

After some three years' interesting and satisfactory employment of women on fuses, they had introduced into their main works the use of women trained in the fuse works on capstan lathes and milling machines and other similar machines, where work could be sent up to them from the tool-room, and where the work was largely repetition work. And there again they had certainly found that the assiduity with which they applied themselves, and their disregard as to a supposed maximum of work to be done in a given time, were most excellent. But when they had tried to employ women to fit together the parts of a more complicated machine—a machine costing much more as a single machine than a fuse, and being produced in, say, hundreds per week while in fuses one thought in thousands—their experience up to date had not been so satisfactory. He was speaking now of skilled fitting, where, before the parts of a machine could be fitted together, it was necessary to do a certain amount of accurate fitting work either by the use of a small scraper or a very fine file, or by the application of small hand reamers and so forth. They had not found, so far, that they could replace with advantage, for work of that kind, the skilled fitter, even by the best selected girls they had had the choice of. Nor did they find that the girls seemed so interested in fitting work as such as in operating a machine, provided, of course, that the machine was so arranged—as many of them had no doubt found necessary—as to be specially suitable for women. He was speaking, for example, of such cases as this—where a capstan lathe was fitted up for man's work, and a woman was put on it, it was found necessary to lengthen the handles of the star wheel. With due intelligence displayed by the management, they had found in every such case that by slight changes to suit the physique of the women, as by making a stool of a suitable height for the woman to stand on—to which matters due regard should be paid, then, on machine work, he had nothing but praise for the work of women; but their success in fitting had not been so great.

He might mention one little illustration—and no doubt other members had had similar experience—which might interest the

(Mr. William Reavell.)

Meeting. In connexion with certain machined parts, the rate of production had been certainly accelerated after the war by the men engaged on them; but still not up to the maximum output which it seemed to them, with the special appliances supplied to the men, they ought to reach. A quantity of that work had therefore been passed over to the women workers, and some capstan lathes had been fitted up for the purpose, and it was found that the men's output had been much exceeded by the women after acquiring sufficient experience. That was an excellent object-lesson to their skilled men, because it showed them what the women could do, and that their own output, excellent as they had imagined it to be, was not good as compared with the standard set by the women. The women, somehow or other, seemed to be able to "go all out," and all employers would willingly pay men much more money if they would only learn that lesson. One other little incident might be of interest to the Meeting, as showing the adaptability and the bravery of women. In the early days of the war, they in East Anglia, as all knew, had suffered very much from air raids. They had had Zeppelins in East Anglia before they were seen in London. They had not suffered from them lately, while people in London had been more favoured both by Zeppelins and by aeroplanes. Having made what they imagined was a satisfactory bomb-proof shelter in the basement of their fuse-shop, and having arranged for suitable lighting when the factory was closed in times of air-raids, they had found to their delight that the air-raids did not disturb the women workers in the least. They were very fortunate in having as one of their supervisors a lady who had been a professional singer before the war, and she at once organized concerts on raid nights. He had been down there two or three times in the middle of the night in times of air-raids, when warning had been received, and on each such occasion he had found a delightful concert was in progress. The electric lights were all shut off, and the women were singing, with candles in sconces round the basement—there was no other light available—and paying no attention whatever to the raids. Arising out of this, a most excellent choir had been formed, which had given some

capital concerts in the town for the benefit of wounded soldiers, by means of which a considerable sum had been raised; and he had always regarded this as a splendid example of the bravery of these women in facing those very difficult circumstances, without any fear.

Mr. E. R. Dolby ventured to suggest, with regard to Mr. Reavell's very interesting remarks, that the term "assembling" had already been most usefully employed to connote the act of putting together the finished parts of any object. He thought the use of the term "fitting" might well be limited to describe the final removal of material by hand to render the parts fit for assembling.

Miss O. E. Monkhouse, in reply, said she was rather fortunate in having to meet very little, or she might almost say no opposition. She had come nerved to meet a serious struggle, but was glad to find that no courage at all was needed on her part! There were, however, one or two points upon which she would like to say a few words. Several speakers had either stated definitely, or implied very strongly, that women could never be what might be called engineers proper. She was not going to hold a brief for women as engineers, but at the same time would like to point out that the remarks made by some of the speakers, though intended to prove that women could never be engineers, only went to prove that there was nothing to prevent a women becoming an engineer, provided she had not got the usual domestic claims upon her time. Mr. Wicksteed, for example, had stated quite definitely that a woman could not be an engineer. But she would refer them to his remarks. He stated that his women had improved in health and strength since they had been with him, that as they became better disciplined and more experienced, their work had improved, that things now were going on as nicely in his factory as formerly they had gone wrong; he even went on to say that scrap in his factory had been reduced to one per cent. Now all those remarks testified to the mental fitness, the physical fitness, and the commercial value of the woman worker.

(Miss O. E. Monkhouse.)

Against women's employment no one seemed to have anything to bring except their domestic claims. Those claims, Mr. Wicksteed had particularly stated, made them bad time-keepers, and prevented them from carrying out the full engineering course which would be expected from a boy. Thus, instead of proving that women could not be engineers, he had merely brought out very clearly what everyone knew, namely, that whatever else a woman embarked upon, she had still got to feed and clothe and nurse her men-folk and children. This was a disability in so far that a woman could not live the life of a man and a woman combined, but it in no way proved the mental unsuitability of women to be engineers.

With regard to the charge that women were such bad timekeepers, she would quote the recent returns from a shell factory which gave the average weekly loss per man 5·8 hours as against 2·8 hours per woman. Moreover the manager stated that his figures showed the skilled men lost most time, the semi-skilled and unskilled came next, and the women lost the least time. This factory was not by any means a unique example.

In answer to Mr. Creak (page 226) who claimed that men should have the same care for their welfare as women, women would be the last people to oppose such an idea. It was the one thing which they would encourage. Men should be well fed, and given opportunities to go from the works clean and self-respecting. That was what was needed for them, and what always ought to have been given to them; and it was for the men to see that they had the proper facilities. She would recommend anyone interested in such matters to go down and see some of the dock canteens. They all knew the roughness of the labour there, and the poor conditions under which the men worked. Well, there were now admirable organizations run by the Y.M.C.A., under the able presidency of Lady Askwith, which supplied to those dock workers hot meals at a moderate cost for breakfast, for dinner, and for tea, at places within a proper distance from their work; and the advantage that the men themselves were taking of those organizations for their welfare was very striking. The numbers were always increasing, and the places were becoming self-supporting.

Mr. W. H. Allen and Mr. Proctor among others had spoken of the advantage to be gained by training the women intelligently. There was no doubt of this, and very often the reason why women had not been a success was because the men had sometimes not thought it desirable to explain to them the technicalities of their work, thinking they would not understand them. Many examples could be quoted to prove this point, and the effect of good tuition was particularly noticeable both on the output and the consumption of tools.

Those were all the points she thought it necessary to touch upon, the majority of the speakers, as she had already pointed out, holding the same opinions as herself upon all fundamental points. But before closing, she would like to acknowledge the compliment which had been paid to women by her being asked to contribute a Paper to the Institution. She sincerely hoped that employers and trade unions would see that women were retained in those occupations for which they were particularly fitted, and that more encouragement would be given to them to take up skilled work. They must see to it that women did not degenerate industrially—that they did not become laundry slaves and sweated tailoresses employed largely by undesirable aliens. By encouragement, she meant that they must be given a definite place in our industrial system, with the recognition of the unions, and provided with the educational facilities of our technical schools and universities such as would fit them to rise to the highest places in engineering, chemical, and allied industries.

Mr. Ben H. Morgan, in reply, said he was sorry that the constructive feature of his Paper had not been dealt with in more detail in the discussion, as he would very much like to have had a wide range of views of men of affairs on the question of setting up standards with a view to bringing about some equality in the labour conditions of the country.

Sir Herbert Austin had raised several very interesting points to which he would like to make a short reference. He had said the thought had occurred to him as to whether it paid to train

(Mr. Ben H. Morgan.)
women in view of the limitations that might arise in their use after the war. He (Mr. Morgan) thought that in approaching this whole question of dilution they must always regard it as purely a war expediency and nothing else. They must not emphasize its economic side. It was simply a war measure to meet a very difficult exigency. Sir Herbert Austin had referred to the unequal progress of dilution in his district, and the retarding effect this had on dilution. Nothing could more effectively point to the need for standardizing dilution effort.

Sir Guilford Molesworth had had an unfortunate experience in his contact with trade unionists at Crayford, and he would like to make the point that, speaking generally, the Ministry of Munitions had received the most loyal support of trade unionists in bringing about the wide employment of women in this country, and that whatever co-operation might have been received from employers whatever the Ministry of Munitions might have done, and whatever organizations it might have set up, it could never have brought about the employment of nearly a million women without the most strenuous and yeoman assistance on the part of the trade unionists, who had actually trained the great majority of these workers themselves in the factories. After all they heard a lot of local obstructions and so forth—and there were unfortunately too many cases—but the great body of workmen in this country were absolutely sound in supporting any measure to win the war.

Miss Anderson, probably the greatest authority on women's work in the country, had raised a very interesting point. It was a truism almost—although he thought it was not always realized—to state that it would be found in the long run that efficiency in production would always coincide with the greatest consideration for the health and welfare of workers.

Mr. Reavell had referred to fitting, but he thought he had in his mind assembling, with a certain amount of fitting. What he had referred to in his Paper was bench fitting, such as the shaping of parts with the file small arms and machine-gun parts involving a great deal of file work. He thought he had now covered most of the points raised, and it only remained for him to express his very

deep appreciation of the cordial way in which his Paper had been received.

Discussion in Birmingham, on 9th May 1918.

The Chairman (Sir Gerard A. Muntz, Bart., *Member of Council*), said that, as one of those who had had to try of late to work up to standard conditions, he had been extremely interested in both the Papers. The Paper of Miss Monkhouse was peculiarly instructive as imparting the views upon female labour of a lady who had had a great deal to do in the active organization and inspection of the same under Government supervision. Miss Monkhouse had spoken of the opposition which the women and girls had experienced in the shops in the beginning, and he was quite able to confirm from his own experience many of her statements under this head. He was glad to say, however, that he had not found the hostility to be so rooted among the average male workers as it had been repeatedly exhibited by many of the foremen. He was equally pleased and surprised when he introduced women supervisors into the shops to find what a rapid improvement almost immediately followed, both in the maintenance of superior order in the shops and also in the character and rate of the work turned out. His experience led him to agree with the pronouncement of Miss Monkhouse that "women should be controlled and organized by their own sex if the best results are to be obtained." He felt it to be absolutely essential to establish women control; it was scarcely natural that women should be properly controlled by men, and certainly male foremen in the shops were by no means the success which was provided by women supervisors. There was a sex sympathy between a woman supervisor and her female workers that was quite impossible in respect of women controlled by men.

Mr. Morgan had advocated, at the close of his Paper, that the Institution of Mechanical Engineers should establish a Committee to

(Sir Gerard A. Muntz, Bart.)

study and report upon women employment in engineering works, the best method of training them, the training of discharged soldiers (with special reference to the employment of maimed men), etc. He could not say that he was greatly in favour of the appointment of such a Committee. If there were more time than now to take it up it might be a very excellent thing, but there was no getting away from the fact that any such inquiry, to be of a representative character, and for its conclusions to be at all reliable, and of a sort to afford a guide for the engineering trades as a whole, would be a very big undertaking. The inquiry would of necessity have to cover a very wide field, embracing in its course all classes of female production in every kind of engineering work; he scarcely knew where such an investigation would begin, and certainly he could not prognosticate where it would leave off. He felt that employers were likely to resent too much internal inquiry at the present time into what they were doing. It should be remembered that British manufacturers were very jealous of their prerogatives, and he was afraid that even to-day this conservatism—or they might call it what they liked—had not vanished. Still, if the Institution could appoint a Committee of limited powers, with the object of accumulating information rather than of trying to conduct any set investigation concerning what was going on in various parts of the kingdom, bearing upon the employment of women and girl labour in the production of engineering work, a very useful purpose might perhaps be served. The experience of individual concerns would then doubtless receive a collective value, and the matter so set out would at least be very interesting.

Upon the question of female labour generally, he thought that it was becoming fairly established that properly trained women could do as good work as male operatives, and in many lines much quicker work. The superior "nimbleness" of the sex had in the past three years shown itself in numerous workshops, though previously the quality had been supposed to be confined to domestic management. He could not refrain from saying how intensely he admired the way the women were working in the engineering shops to-day all over the country, and he would like to appeal again

for the much more universal appointment of women supervisors. The full capacity of female labour was not yet known in Great Britain, and he felt that the good which might result from the establishment of like-sex foremen was unlimited, as well as being the "right thing."

He desired to congratulate both Authors upon the excellent manner in which they had treated their theses.

Mr. E. W. Anderson, in opening the discussion, criticized what he termed the "omission" in Mr. Morgan's Paper to contain any reference to the employment of female labour in the manufacture of small-arms ammunition. In Birmingham many thousands of girls were employed on this work, and had been so for years past. They performed most excellent service, and the business seemed to be one for which they were especially fitted. They were also most efficient in making and setting the tools for the machines which were required for small-arms ammunition manufacture. At the concern with which he was connected the management had gone much further than this, as it had been found that women were even capable of making gauges required for small-arms ammunition work. Within the last few days two gentlemen from Woolwich Arsenal had expressed their great surprise at what they had witnessed in this connexion on their premises.

The Authors had shown themselves strong advocates for the appointment of women supervisors of women's labour. In this particular he agreed with them, since he believed that such a provision was a great advantage to the workers, and at the same time assisted in the work being got out with the greatest rapidity and perfection.

Mr. John Nasmith expressed his surprise that people looked upon the employment of women in engineering factories as something new. His first experience in dealing with women workers was fifteen years ago, when he joined the British Westinghouse Co. at Manchester. This Company was then making considerable use of women labour, chiefly with respect to the winding and

(Mr. John Nasmith.)
insulating of armature and transfer coils, but, in addition, they had a large number of women employed on capstans. However, owing, he believed, to the great variety of work which was dealt with by the firm, and the consequent amount of supervision which the women required, they ceased to be employed on capstans. On the electrical side, however, they were extremely efficient, and when he left the firm they were employed on a number of operations of a repetition nature, which they carried out very successfully.

He was of opinion that it would not be wise to expect too much from women, particularly where the output was of a varied nature. His experience had been that it was almost entirely on repetition work that they had done such excellent work. He thought that girls with five or six years' training would not be so useful as youths who had had the same training, and that in work requiring originality and inventiveness they would be of very little use. At the British Westinghouse Co.'s Works a suggestion system was in operation, and during the seven years he was there, although they received many suggestions from men, they never had one from a woman. His opinion was that women could render the most excellent assistance on work of a repetition nature, but their services would have to be made use of with very great caution on other classes of work, and it would be advisable that they should thoroughly prove their ability before they could be expected to take the place of the skilled men. He suggested that a very serious situation might result if the skilled men were taken out of the shops before the women were found suitable to replace them.

Mr. J. FEARN said that the Birmingham Small Arms Co. had at first met with some opposition from their male workers in the dilution of machine-gun and rifle manufacture by the employment of females, but experience of the women's presence in the shops had worked wonders, and both classes of labour were now working side by side in the same shops and under the same foremen. It had not been found necessary to engage women foremen. Equally successful

had been the employment by the Company of women on small-tool work, of which the firm turned out great quantities. In their small-tool factory male labour had been supplanted to a very large degree, and there had been no need here again for any change of sex supervision. He would read to the meeting a communication which he had received from the manager of the factory just mentioned, in reply to his (the speaker's) request, giving his experience. The communication was as follows :—

"Great care was exercised by us to choose superior types of girls. The majority of those chosen had no previous experience of factory life, many being domestics, shop assistants, and girls at home. Speaking generally, all girl dilutees had to work in shops along with men, and lack of discipline never proved serious, due probably to the institution of works matrons simultaneously. The novelty created at first soon disappeared. The girls that were chosen to work in tool departments were given one hour weekly tuition in the use of rules, scales, micrometers, verniers, etc., and the majority showed remarkable capacity to understand. We found some evidence of opposition on the part of men, but this was never serious, probably because they found that the girls showed so much aptitude for the work, and the fact that their presence as dilutees was indispensable. We have found that undoubtedly girls show evidence of fatigue from long working hours, and we believe that short hours show greater efficiency. The institution of Works Canteens has undoubtedly improved the general health of women, because whereas before women frequently made their main meals of "relics from home," etc., they can now obtain a hot wholesome meal at both breakfast and dinner time for a total daily cost of about 1*s.* 4*d.* Example of intricate work—rifling cutter box before war made by men (nine hours) now entirely made by women (1½ hours)."

Respecting the manager's statement in the foregoing communication about the works canteens, he (the speaker) would like to add that the Company regarded the giving of free meals as a very objectionable practice indeed. Supplementary to the manager's communication concerning intricate work, he would like to impress how delicate was the operation of rifle-cutter box manufacture, yet the manager's statement would have been noticed that these were now wholly turned out by girl labour. The members would have been struck by the marvellously short time in which the women did the work compared to the men, but this

(Mr. J. Fearn.)
was simply the result of organization. Some other classes of work besides those mentioned by the manager now fell to women, as for example, small cutter making, including the setting up of their machines, and the women had been specially trained for these jobs.

The proposition of Mr. Morgan that the Institution of Mechanical Engineers should set up a Committee to report upon the best methods in each engineering industry of introducing woman labour, and cognate matters, would, he was afraid, be viewed with very grave suspicion at the present time. The Meeting would recognize that it was a matter of exposing manufacturing methods, and he was very much afraid that firms would greatly dislike and probably refuse to give information respecting their works' inside operations. If such an appointment were delayed until after the war it would be a different matter, and many of the objections to which he had referred would disappear. He did not anticipate the present extreme shortage of labour after the war, since of course the men would be returning home, although simultaneously the women would be very largely wanted back in their homes. By then, too, the rate of machine production would have been largely increased by the improvements in manufacturing methods now going on. Wages, although not the same as to-day, would be very much higher than in pre-war times, and, supposing each was equal in their capacity of output and skill, he did not suppose it would very much matter to an employer whether his workers were called skilled or unskilled. There was an enormous dislike to Government interference in the engineering trades, wherever it could be possibly by any means avoided, and he rather feared that if this Committee started to inquire at the present time there would be grave suspicion, whether well founded or not, that the Government was seeking information which producers would much prefer to keep to themselves, and his objections were based largely upon this suspicion.

Mr. W. DEFRIES did not propose to offer any observations of his own on the subject under consideration, but wished

merely, availing himself of the privilege of an old member of the Institution, to suggest that the discussion up to that point seemed to have avoided the really constructive proposals of Mr. Morgan's Paper. Mr. Morgan was clearly of opinion that after the war there was bound to be a much greater employment of female labour than before. He did not himself see how any man of experience, in daily contact with the engineering trades, could entertain any different view. It was even clearer that, if during the war more women were not employed in the shops than were now there, it would be impossible to produce munitions upon the needed scale, and at the same time to satisfy the demand of the services for men. Mr. Morgan therefore asked them to consider whether means could not be found for making better use than at present of the country's men, women, and plant, and he had presented some exceedingly thoughtful suggestions for the consideration of master engineers. The speaker believed it would be manifestly to the advantage of the trade that those suggestions, coming from so authoritative a source, should be considered carefully. He offered no opinion of his own as to whether and how far Mr. Morgan's proposals were or were not expedient; that was a matter which each firm could best determine for itself, and solutions that might be possible for one firm might not be for another. But it was clear that the matters put before them that night would have to be faced at some time or other, and a deliberate judgment pronounced upon them. Under these circumstances he could quite understand Mr. Morgan's evident anxiety to secure some pronouncement of opinion from the meeting that night, and he begged to support Mr. Morgan's appeal for an expression of the views of members, not so much on his history of the past as on his proposals for the future. Prompt criticism of the proposals by persons having the practical acquaintance with their subject matter that was possessed by members of the Institution, would not only bring out such objections as might be seen to what Mr. Morgan was proposing, but would also give the best chance of solving the urgent and difficult problems that he was attacking.

Mr. R. H. PARSONS said that, in his view, the most important feature of Mr. Morgan's Paper was the emphasis laid upon the duty of engineers to utilize labour efficiently, particularly at the present time. Labour-hours were the basis of all production, and the present shortage of labour rendered it all the more essential that every factory should give an adequate return in output for the labour-hours consumed. A few years ago, when labour and particularly skilled labour was cheap and plentiful, it could be lavishly employed without unduly increasing the cost of production. Now, however, it was perhaps the most important national asset, and our existence both during and after the war would depend more upon how much useful productiveness could be obtained per unit of man-power available, than upon any other single factor. Hence, engineers must become accustomed to think in terms of output per man-hour, and must take advantage of every method of manufacture and scheme of organization which would increase this quantity. This idea in no way involved either the underpayment or overwork of the workmen. He (Mr. Parsons) believed that in the United States the productivity per man-hour was in general much greater than in this country, whereas the workmen there earned more money, and were no more fatigued after a day's work than their confrères in this country. The American employer moreover succeeded in making very satisfactory profits in spite of the high price he paid for labour. It was almost entirely a question of proper organization, methods, and machines, and he was glad to hear the value of proper organization so remarkably demonstrated in the remarks of Mr. Fearn, who gave the experiences of the Birmingham Small Arms Co., in connexion with the manufacture of rifles.

In the old days there was too little trouble taken in the organization of work in engineering shops. Nobody considered beforehand exactly how long each operation on a part should take, or with what machines and tools it could best be performed. The details of manufacture were left too much to the ideas of the foremen and mechanics, and the management exercised far too little knowledge or control of the actual processes of manufacture.

The time for such indifference had entirely gone by, and the intelligent direction of details on the part of the management was absolutely necessary if the highest productivity was to be obtained. After peace was declared there would not be anything like the amount of highly skilled labour available before the war. Apprenticeship had suffered, and many of the returned soldiers would be unable to follow their previous skilled occupations by reason of wounds or mutilation. This situation would compel engineers to organize their factories so as to get a greater output per man-hour than ever before, if they were to hold their own under the intensive international competition which would follow the declaration of peace.

He considered the question of the efficient utilization of labour to be so vital to our success in this war that he supported most heartily Mr. Morgan's suggestion that standards of labour-hours permissible for all munition contracts should be established, and no firm should be allowed to use labour in excess of what was necessary under good organization and modern methods of manufacture. The State should be in a position to justify its labour standards by indicating in detail how the required output per labour-hour could be obtained, and it should have no hesitation in refusing labour, material, or contracts to firms who would not bring themselves up to the desired standard of productive efficiency.

Mr. W. A. Binks found it rather difficult to criticise the Papers, as both were so well thought out. But the suggestion for a Committee of the Institution to report upon the best methods of introducing women into their engineering works, and the best methods of training them held the field as the most practical outcome of Mr. Morgan's communication, and it was one which would be certain to excite wide discussion. The suggestion, however, was not so easy of adoption as at first might appear, or even as Mr. Morgan seemed to imagine. He (the speaker) rather agreed with Mr. Fearn that there were difficulties in the way which at any rate would dictate the wisdom, even if it did not impose the actual necessity, of their going slowly in this matter, and he spoke with a

(Mr. W. A. Binks.)

Coventry experience. Anything in the way of compulsion especially would be sure to frustrate the very ideal which it was proposed to attain. It could not be forgotten that engineering employers, and in fact every type of manufacturer in this country engaged in business in a large way, were of a very conservative temperament and the last thing in the world they would submit to, if they were strong enough to resist, was interference in the way of conducting their business. It would be necessary therefore to go to work very carefully, and if the imparting of the information sought by the Committee were purely a voluntary matter on the part of the firms approached, he could readily understand that their difficulties would be lessened. There was no doubt that information under the head of costs especially, which the Committee might secure, would be very valuable at the present time as a guide to firms intending to put into action yet more the woman-dilution principle; and it was also not yet sufficiently known what were the exact capabilities of woman and girl labour in engineering matters, and how their performances contrasted with that of men. There was a desire on the part of many firms to possess some specific information under these heads. They would have to be careful, and not seek to go too fast, and avoid as far as possible anything which might savour of compulsion. He was persuaded that the operatives were very much of the same way of thinking as the employers on this and kindred matters. It was well to recollect that Germany was not England in propositions like this. What would be permissible and tolerated in Germany would be quite impossible in this country, and he was happy that it was so. In Germany manufacturers had no option; they had to do as they were told, but it would be a sorry day if things ever came to that pass in this country.

He was rather afraid that women dilutees would be found lacking in initiative when employed in engineering workshops. His experience of woman labour was limited; still, so far as he had been able to judge, this was the opinion he had formed.

It might be of course that when they had attained the habit of life in an engineering shop, this present defect might gradually

become removed by reason of the new influences and conditions which would be brought to bear upon their brain power, but so far there could be little doubt that, in other than exceptional cases, women lacked the inventive faculty. He would like to hear the experience of other firms upon this point, and any information which the proposed Committee could collate under this head would be a valuable asset. Many manufacturers were anxious to get all the assistance they could respecting the setting-on of female dilutees, but they hesitated concerning the means to obtain the best results. They were now passing through an entirely new period of the labour problem. Manufacturers and workers at the present moment were working more amicably, especially those who realized the menace of the enemy. Much depended on taking advantage of present conditions, both as regards the present safety and future prosperity of the country.

He was very interested in hearing the testimony of Mr. Anderson respecting the successful employment of women as gauge-makers (page 287). Such evidence was most gratifying. This was a department of skilled work to which he quite believed women might well be trained to a much greater extent than at present. Upon the subject of the employment of female labour generally, no one could doubt that the objection which was taken by the male workers at some works to this dilution largely vanished upon better acquaintance with the novelty. Experience had amply shown that, after the girls had been working in the engineering shops for two or three weeks, or it might be a somewhat longer time, the initial opposition from the men working alongside them died down. Better than this, the opposition was soon succeeded by a feeling of comradeship and chivalry which made the men anxious to do their best for the women and pilot them over difficulties which they might meet with in the course of their work. The younger men especially often proved themselves particularly chivalrous in assisting the new dilutees to surmount difficulties. If the Institution could appoint a committee to collect data on the experience of the past few years, and to endeavour to develop the more successful experiments ; to encourage a far greater use of jigs

(Mr. W. A. Binks.)
and gauges; and encourage a more systematic training of women, he thought this would be far better than to wait for a crisis and then compel the Government to pass panic regulations.

Mr. S. J. DAVIES noted with approval the statements in Miss Monkhouse's Paper that the industrial efficiency of the country in respect to production at the present time had been greatly increased by the introduction of woman labour. Anyone who had experience of employing women, knew of the great advantages possessed by women of education. The need for improvement in the education of girls had been emphasized by the events of the last three years; and engineering employers should interest themselves in the question.

It had been stated by Mr. Fearn (page 289) that the Birmingham Small Arms Co. gave to the women in the small-tool factory an hour's tuition weekly in the use of gauges and other measuring tools which they had to use in the course of their work. This was a proceeding which might very well be extended to other firms, and he would prefer indeed that double this amount of tuition was imparted, an expenditure for which he was sure the firms undertaking it would soon be recouped by the improved quality of the work turned out and its more rapid production. The better education of women and provision for its continuation should be considered among the other points to be dealt with by the suggested committee of inquiry.

Mr. BEN H. MORGAN, replying to the discussion, regretted that the criticism of his Paper had not centred mainly around the suggestion of the desirability of finding and establishing standards of labour dilution and labour efficiency. Sir Gerard Muntz had expressed only a halting approval of the proposal for the establishment of a Committee of the Institution to study and report on the best methods in each engineering industry for the employment of women and discharged soldiers, and had thought that its appointment might be undesirable if it covered too wide a field of inquiry. If Sir Gerard's opinion were found to be general,

the Committee might confine its attention within narrower limits, perhaps, than his Paper suggested. If the inquiry were limited to a consideration of the two matters of (1) women's work; and (2) the employment in industry of discharged soldiers, it might do much useful work. Unless engineers themselves initiated some inquiry, under certainly these two heads, he felt sure they would be making a serious mistake. It would be a great error to ask the State after the war to decide these matters for them. Soldiers were being discharged in ever-increasing numbers, and the bulk of these men had been wounded, and many had lost limbs or their sight, either partially or wholly. Nothing at present was being done to study how their places were in future going to be filled, in cases where they could not return to their former occupations, what occupations men with certain injuries were most suitable for, and what devices and appliances were necessary for their training and re-employment. All these things called for minute study and discussion—and it seemed to him that engineers would be so deeply affected by the new industrial situation that they could not act a moment too soon in setting up some machinery for solving the problem.

Mr. Anderson, in his criticisms (page 287), had regarded it as an omission that the Paper had made no reference to the employment of women and girls in small-arms munition manufacture. It was not, however, an oversight; the Paper dealt with the problem of female dilution of labour as it had developed since the outbreak of war. The employment of girls as small-arms ammunition makers had been a pre-war occupation, and did not therefore come within the purview of his communication. Mr. Anderson had spoken of the success with which his company were turning out gauges by woman labour, and had mentioned that Woolwich inspectors had expressed surprise at finding that such labour was capable of this performance. He (Mr. Morgan) could quite understand the surprise of the inspectors. But he knew that at Mr. Anderson's factory some very clever work by women in gauge-making was being done.

Mr. Nasmith (page 288) had described women as mere

(Mr. Ben H. Morgan.)
copyists, and had expressed doubt as to whether they would succeed much beyond this. He assured him that this was a very great misconception, though, he was bound to admit, a misconception which was very widely prevalent. The reason why female dilutees had been employed so far mainly, perhaps, in repetition work in engineering shops, was that they could be most readily employed on those jobs—on work which was urgently required by the nation and which would give the biggest output in the shortest time. Mr. Nasmith might be surprised to know that a woman could be trained as an all-round skilled worker in less time than a man. It was a fact, and one which admitted of no explaining away, that a good many women to-day could be classed as skilled turners and fitters after only three years' training. He would not deny that there was some truth in the argument that women did not possess the initiative faculty in engineering work to the same degree as men. He was prepared to admit, as the result of experience in the shops, that it had now been established that on non-repetition work women did not give quite the same output as men. On repetition work, however, female labour had been a discovery; on nearly all classes of munition production they had exceeded all pre-war records of male labour. Nevertheless, he was very pleased with the criticism which had been indulged in, since it was only by a free and fearless interchange of ideas that they could arrive at sound basic truths and possess themselves of any advance in knowledge and practice concerning female work.

He was seriously afraid that in considering the female labour problem, sufficient realization was not often had to the probable long duration of the war. He did not wish to pose as a prophet; yet he was fairly convinced that the country still had before it a very long period of armed conflict, possibly running into several years. Face to face with this situation was the admitted fact on all hands that the shortness of labour was very rapidly increasing. The whole question of a more drastic handling of the labour problem as it at present presented itself would have to come up for the consideration of the Government at no distant date. He had

listened to the remarks of Mr. Parsons (page 292) with the closest attention. It was perfectly clear that something in the way of rationing of labour, in the same way as works materials were rationed, would have to be attempted by the State. The variation of practice concerning women employment in even the shell-making shops in the Birmingham area was absolutely surprising. Some employed practically no women at all, while at other shell-producing concerns female labour formed something like 90 per cent. of the total workers. Again, some of the tool rooms in the Birmingham district had scarcely any women on the ground, while at others women and girls formed 25 per cent. of the total. He quite agreed with Mr. Parsons that all this would have to be altered in the early future, and that labour dilution methods would have to be strictly utilized. He would like to say to the credit of works proprietors that he had never yet found a firm which was not willing to make sacrifices when called upon by the State, always providing that other firms—or, if the term might be allowed, other competitors—were compelled to do the same. And he entirely believed that this patriotism by master engineers and other manufacturers could continue to be relied upon. The difficulty in the future lay in the fear of exceptional treatment. Obstacles were, and would continue to be, placed in the way of the employment of female dilutees by individual firms, if other firms in the same district, and perhaps only a little distance away, refused to employ women. But providing the same law were to be made applicable to all firms, he did not conceive that any difficulty would arise. Man-power economy was one of the problems which would certainly be made, he believed, a matter of compulsory solution sooner or later.

Some time ago the Ministry of Munitions established a labour dilution standard for the manufacture of shells, up to 4·5-inch size. In the contracts which they placed for this size of shell, it was compulsory on all contractors to employ 80 per cent. of female labour in the production. In the last issued Government Report dealing with labour in controlled establishments, particulars were given of ten factories devoted to the manufacture of 18-pounder

(Mr. Ben H. Morgan.)

shells; and, with only one exception, all these ten firms had employed more than the standard dilution. The lowest percentage was shown to have been 81 per cent., and the highest 86 per cent. The machinery and plant employed at these ten works showed a most remarkable variation, and yet the labour dilution effected had been nearly equal throughout. It was an astonishing thing, which had been abundantly shown by statistics, that in most of the National Shell Factories the output had increased rather than decreased with growing female dilution. He would now illustrate the case of the manufacture of 9·2-inch shells, respecting which no compulsory dilution of labour had been attempted. In the Report already quoted three factories were specified as manufacturing the larger shell just spoken of, and the percentage of women employed was respectively 4·2 per cent., none, and 49 per cent. Here then was an enormous difference clearly established. Of his own knowledge, he (Mr. Morgan) could testify to a munition works on 9·2-inch shell where the female labour employed amounted to no less than 90 per cent. of the total, and in another shop equipped with the latest tools, not a single woman was employed.

From the figures which he had quoted, the Meeting would recognize how much more satisfactory it would be in the end to arrive at something in the nature of a standard of female dilution rather than that the present intensive differences should continue to be perpetuated. A common standard would ensure not only that the sacrifices made by individual firms should in future be equal, but that each manufacturer would be in a far better position than now how to plan his individual works organization to a successful issue. Further, the Government and contractors would be able the more successfully to estimate the exact time which the execution of any one contract would occupy; and each party to the contract would know the respective cost and profit.

He would like to add that he was quite of the opinion expressed by Miss Monkhouse that the employment of women would materially increase the future industrial efficiency of the country. Previous to the war there was a very large proportion of the population consisting of women, who were, for the most part,

non-producers, and totally unprepared in education and training of both mind and body for taking a useful part in the world's work; but the war had altered all this, and to-day it was a revelation to very many people how efficient these dilutees had become in the short space during which they had been on trial. It was no exaggeration to say that England stood a free country to-day, because of her women's noble efforts in the realms of engineering the industry.

On the motion of Mr. A. E. A. Edwards, seconded by Mr. R. B. Askquith Ellis, a hearty vote of thanks was passed to Sir Gerard A. Muntz for presiding, the proposer remarking that Sir Gerard had had a large experience of women and girls' work in association with the production of war material in the Birmingham district. They could therefore have not possibly had an abler chairman for the Meeting that evening.

The Chairman (Sir Gerard A. Muntz, Bart.), in acknowledging the vote, said that it had been rather against his conscience to occupy the Chair, since, owing to the very many duties with which the Government had kept him active during the past four years, he scarcely thought he had been able to attend the Meetings of the Council in London more than once or twice, which was to him a matter of considerable self-denial and regret. He had felt, however, that the question of woman's work since the war was one which was not generally sufficiently appreciated by the "man-in-the-street," and he had therefore been anxious to do anything he could to show his great interest in the Papers which had been read. The patriotic manner in which women had come forward in the nation's extremity to occupy the places of the men from the shops, who had gone to the Front, was beyond all praise. Their conduct had been magnificent, a fact which could not be too widely recognized. The women had made extraordinary efforts, and they had surprised everyone by the capacity which they had shown. Without their aid, it would have been impossible to continue the carrying on of the engineering and manufacturing interests of the

(Sir Gerard A. Muntz, Bart.)
country, and as for their work as munition producers he had no hesitation in saying that but for the women and girls the country would have "gone under."

Upon the motion of the CHAIRMAN, the best thanks of the Institution were awarded to the Birmingham University Authorities for allowing the use of their Lecture Theatre for the purpose of the Meeting.

Discussion in Manchester, on 10th May 1918.

The CHAIRMAN (Dr. EDWARD HOPKINSON, *Member of Council*) said that this Meeting of the Institution was a somewhat remarkable one, as also were the corresponding ones held in London and Birmingham. It was the first occasion in the history of the Institution on which a Paper had been read by a lady. What that might connote as regards the future of engineering he did not know, nor was it their present business to inquire, but in passing it was fitting to say that it did mark, seeing that both the Papers were essentially War Papers, the splendid part women had taken in the prosecution of the war.

The occasion was also a special one, because the Council in selecting the two Papers had gone somewhat beyond what were previously regarded as the usual lines on which Papers should be written and subjects dealt with. He welcomed this, as he felt strongly that the activities of the Institution ought not to be limited too strictly to purely technical accounts of engineering work accomplished, or new plant, new devices, new inventions or results obtained; and that they might be extended to a wider sphere and take into consideration such subjects as labour organization in workships and other broader aspects of the engineering business and profession.

Passing to the particular subjects of the two Papers, he hoped that those who took part in the discussion would restrict their remarks to their own experiences. The employment of women in engineering shops on the scale that they were now being employed was a great national experiment, and none of them could forecast its future development in the least degree. They were almost debarred by agreements made by the Ministry, upon which the effective employment of women was based, from attempting to formulate schemes for the application of the present development to future work. That made it all the more important that all the data it was possible to obtain from the experiment now going on should be duly recorded in serviceable form. But in recording the experience gained in particular workshops, there was this difficulty, that those experiences frequently had not a common denominator. One person might achieve success in a particular line and attribute it to causes which were not the real causes. With the same causes in operation, another person might have met with failure for reasons which were not apparent. In that respect the Government Departments, and especially a Department like that over which Mr. Morgan presided, could be of great service. A Government official in Mr. Morgan's position had access to all engineering works and to all their records, and he could reduce the work in the different shops to a common denominator and make sure that the conditions under which the results were obtained and recorded were the same.

Mr. Morgan suggested that labour efficiency standards should be set up for particular operations in various classes of work. It would be most valuable to find out the labour cost on, say, a 4·5-inch shell, assuming that the best of every process in use throughout the country was collated. An eclectic score was an extraordinary record and very different from that of a scratch player. None but a Government official having access to all works could put together an eclectic score for any piece of work, and that was what should be done, because it gave the ultimate standard to work up to. But working conditions varied so much in

(Dr. Edward Hopkinson.)
different shops that comparisons were often very difficult. For instance, he noticed that the 6-inch shell was held to be suitable work for women, having regard to the weights to be lifted. He was horrified at the idea of women having to lift weights of over 60 lb. His own experience was based to some extent upon Lancashire factory women, who, no doubt, had not the physique of women drawn from country districts, and he would say that the 4·5-inch shell, having a gross weight of 55 lb., was about the limit which women could lift without risk to physical health. There again it might be that the common denominator was not present, and when people spoke of the 6-inch shell being worked effectively by women it meant that the lifting work (as it ought to be) was done by machinery.

The work of women in engineering factories was no new thing. In electrical work women for a long time had been engaged in such work as armature winding. Many firms had large experience of the employment of women. But its enormous extension had brought about many things in its train, which he thought were reacting upon the organization of engineering shops in general, and reacting altogether for good. It had introduced the Women's Welfare Superintendent. That, he believed, had had an exceedingly good general effect throughout shops generally. It had brought employers to realize, and the Government had emphasized it in every way possible, the importance of welfare conditions generally, and perhaps in some instances under pressure from the Government, perhaps from the fact that they knew that they were employing women to a much larger extent than previously, employers had responded by the introduction of better hygienic conditions which had come to stay, and would be of great advantage to the engineering trade in the future after the war.

Mr. G. E. WINDELER said that in their own Works they had, through the intervention of the Ministry of Munitions, adopted women labour to some extent. The Works were largely concerned with the manufacture of engines, and about eighteen months ago one Department of the Ministry approached his firm to design an

engine for a special purpose in such a manner that it could be produced in large quantities, with a fair proportion of unskilled labour. The best means of production were to be utilized, such as jigs, special fixtures and devices. Four firms in the Manchester district were asked to co-operate, and he was glad to say that this co-operation had been carried out in an excellent manner, and that some of the points laid down by Mr. Morgan in his Paper as to standardization regarding methods of production in various Works had been more or less adopted. This was carried into effect by a free interchange of ideas as to the methods of production proposed by each of the firms, and although these various firms were rivals in business before the war, arrangements had been made for each to visit the others' respective Works and see what they were doing, and their respective staffs to interchange ideas freely for the development of production of the various parts. This naturally resulted in practically a standardization of the methods of production in each of the Works and an accelerated output of the engines required.

When they first introduced women labour they mentioned to the workmen in their employ that vacancies were available for women labour, and suggested that their own relatives might make application for the various posts. This was attended with very satisfactory results, and care was taken to allocate the women labour in each particular department so as to see exactly how they were able to cope with the work. For instance, they were employed in the tool stores, in the issuing of tools to the workmen, and very quickly learnt the names of the various tools, such as taps, reamers, mandrels, and similar light classes of tools, and the distribution of same. They were also employed in the tool room on hand-scraping work, small shaping machines, drilling machines, and tool-grinding machines. As the introduction of this class of labour increased, they were put to work on small brass finishing lathes, milling machines, drilling machines, precision grinding machines, as labourers on the floor for keeping the floors clean, and moving about light classes of work. They were also employed on cleaning and painting the interior of engines, and also cleaning down and

(Mr. G. E. Windeler.)

painting engines after trials. They were then used to operate electric cranes from 10 to 20 tons capacity. This was a duty about which the firm felt somewhat nervous, so the women were trained in a separate part of the Works where the lifting of parts was carried out under quieter conditions; and someone was employed to train them who knew thoroughly the working of the crane and who would illustrate simply how it was operated. The results of the experiment, so far as the crane driving was concerned, had given much better service from the cranes than they had had before. The women seemed to be much more attentive and on the lookout for the signals and necessary requirements of the shop. If there were any exceptional weight to be lifted or turning over of heavy parts to be done, the firm generally arranged for one of the men supervisors to help the women. One difficulty occurred and had to be thoroughly considered, and that was the provision of facilities for enabling the women to climb to such heights to get on to the cranes. This was rather a problem, and after careful consideration, a small portion of the floor at each end of the shops was appropriated, and a suitable reasonably-graded staircase and platform were provided so that the women could climb up to the crane tracks easily, and readily step off on to the crane seats. The result of this arrangement had been very satisfactory.

Later, an extension for a more rapid production of the various parts was undertaken, and practically the whole of the work carried out in this portion of the Works was done by women labour. Various types of machines were grouped together, such as drilling machines, milling machines, gear-cutting machines, and semi-automatic bar machines. The women were supervised by skilled charge-hands or assistant foremen, who were attached to the staff. As setters-up, superior apprentices were utilized, but in some cases this class of labour very quickly became unsettled, as the work, no doubt, was monotonous. The idea of using these apprentices was to enable promising young men to prove their initiative and ability to organize or assist in the organizing of work and handling of workpeople. In the fitting-up work, woman labour was used for studding bedplates and columns, and fitting up small parts. It was

also utilized for filing off the raw edges formed by the various machining processes and for the assembling together of small fitted work. It was found in these sections that a woman charge-hand was quite satisfactory. Again, very satisfactory results were obtained by woman labour in the Inspection Department, where they showed great patience and efficiency in the inspection of work by gauges and micrometers.

When the Ministry decided that dilution was necessary, they assisted them in a very admirable way by pointing out the work which women could be put on to, and at the same time allowed them a reasonable period to bring this class of labour into operation; that is to say, they did not force them to put fifty or sixty women into a Works at one time, but allowed them to be gradually introduced and graded up to the work as they obtained the necessary skill. From the advice received from the Ministry, and the assistance given by the foremen and charge-hands in their works, the results obtained had been on the whole very satisfactory. Of course there had been troubles and difficulties, but these were overcome by patience and diligence, and by studying each difficulty as it occurred and making provision for it.

Mr. Joseph Butterworth said the adoption of women labour had been a great advantage during the war from points of view that had not been touched upon in the course of the discussion. Owing to the scarcity of labour, the individual had not had any need to think about "keeping his job," as the term was in Lancashire. He had absolutely no anxiety about it, with the result that discipline was practically an unknown factor in engineering shops in the Manchester district. In fact, it was practically necessary to go to a man, cap in hand, if they wanted to get anything from him. The output of any standard article had certainly not increased since the beginning of the war, using the same tools and adopting the same methods. One would expect it to be so, because if a man was under no anxiety as to the chances of keeping his situation, naturally his thoughts would unconsciously relax to that extent. In practice that had been found to be so.

(Mr. Joseph Butterworth.)

The introduction of women labour had been a great benefit, and he had been able to make a comparison. Women had been put on a job similar to what a man had been on—a light job but at the same time an accurate one—and he could point to cases where the women did double the work a man ever cared to do. He did not wish to say a woman did the work a man could do, but double the work it was usual for him to do under ordinary methods, and with restricted labour which obtained in all engineering shops in this country under trade union methods. The employment of women had been a very useful factor in breaking down that restriction of production to some extent, and but for that fact, manufacturers would not have been able to turn out several articles they were making, with the same facility and as cheaply as they were doing.

The success of rationing of labour, dilution efficiency, and so on depended upon each firm adopting exactly similar methods, and that was necessary if anything like collateral results were to be obtained. Mr. Windeler had pointed out several instances where the employment of women had proved advantageous, but he was afraid it would be difficult to set up a common denominator, or to differentiate between various firms, because one tool made specially for a certain job would turn out far more work than another tool which had to be used for practically twenty different jobs. A large firm could have a special tool for each separate job, and therefore in that respect it would be difficult to differentiate. In that way large firms ultimately had the advantage, and it was in that connexion that the collaboration of various firms had proved to be one of the finest things ever introduced, and he hoped it would be carried out to a much greater extent than at present.

The old idea of secrecy and jealousy in regard to trade processes and the restriction of production, which was so extensively practised in this country, must go by the board. It was easy to point out those facts to the ordinary working man—he had done it with his own—but it had very little result. Even in the best managed shops it generally cost as much to keep a man going as he was paid in actual wages. If a man were paid 1*s.* an hour, it cost 1*s.* an hour to keep him going in the way of standing charges of

various kinds. If a man would only put forth an effort to turn out double the work every day, he would reduce the percentage of standing charges by one half, because they would be just the same whatever amount of work was turned out. If the American system were adopted, and a man who did double work was paid at time and a quarter, that is, two and a half times the standard wages, the firm would still have something in their pockets in the way of a saving, thus enabling them to compete more keenly for foreign trade. Some method of that kind would have to be adopted in this country, before they got right down to rock bottom as regards the cost of production.

He could not usefully go into details of the various departments as Mr. Windeler had done, but he might say that they had introduced women into their stores, tool room, foundries—both iron and brass—grinding shop, dressing shop, brass finishing shop and pattern shop. In every case their experience had been satisfactory, and they would do their best to continue it as long as they were allowed to do so. It was a thing that would right itself, even if they had to keep to the letter of the agreement that was made in the early stages of the war, to abolish all woman labour at the end of the war. He did not see how that was going to bind a firm who started after the war; if it were found that cheaper production might be obtained by the employment of women, he did not see anything that would prevent a firm starting *de novo* and using woman labour.

Mr. W. W. ADAM said the war had revealed to them many occupations where women could be employed with great advantage, and no doubt after the war they would continue to fill those occupations, because for some classes of work, women were more suitable than men. Some years before the war he had experience of women labour in connexion with a special manufacture, to which it was extremely difficult to train them. Women had to be brought from France and Belgium to teach the English women how to do the work, but after considerable time and expense they learnt it very well, and were now able to do it just as well as the others.

Mr. OSCAR S. HALL said he agreed to a great extent with the remarks made by Mr. Butterworth on the question of production. Every effort should be made in the future to secure unrestricted production in all engineering works, or the country would be relegated to a very low position in the economic world.

Mr. HAROLD SMITH, M.B.E., said the experience of his firm in the employment of girls started long before the war. At that time those girls were engaged principally on light repetition work and on winding and insulating electrical apparatus. The number employed had increased from about 5 per cent to probably 30 per cent of the total employees, and they had been successful mainly on light machine-work, fuses, bombs and shells. Women had also been employed on heavier work, but, as that was more of a jobbing nature and largely on adapted plant, the firm was not able to make the fullest use of them. It was difficult to extend their use to work which was done in pre-war times for commercial purposes, and was now done, in the same form, for direct and very important war purposes, because the men in the shop, to whom the article appeared just the same as that made in ordinary times, had an instinctive objection to allowing dilution on the job, even though it might actually be far more important to the war than a gun or a shell. Many firms had found that it was only on work which was obviously of a war nature, such as guns, shells or fuses, that the men gave that loyal co-operation and help in training women which was absolutely necessary to make dilution successful. On many jobs women had not the *nous* and natural ability a boy possessed, to grasp the nature of the work to be done; if everything was prepared and mapped out for them, they could go on doing it in a repetition sort of way, but they had not the faculty of spotting things when they were going wrong. On piece-work, more inspection of output was necessary than in the case of men and boys; they were very keen on big wages and were apt to slip through work which was not up to the mark. His experience was that they did not keep as good time as men; in fact, he knew of one shop in the Manchester district where it was considered

necessary to have 25 per cent more women on their list than they could actually use, because they always assumed there would be somewhere about that percentage absent, and by making that provision they could keep their plant going at full capacity.

Single women, in his opinion, were much easier to manage than married women. At one time his firm employed a great many soldiers' wives, and they were often rather difficult to deal with, but single girls were more amenable to discipline. Speaking generally, the work for which women were suitable had to be highly standardized; they had really to be made into operators (with everything mapped out for them) and not machinists.

With regard to Mr. Morgan's standards, some of the ideas put forward in the Paper would press very hardly on firms which turned out war contracts on adapted machinery. In the early days they were told, in connexion with shell work, that they must not wait to buy new machinery, but must adapt what they had and make it do the job. That was done very largely in the Manchester district, and firms which adapted their plant to the greatest extent, speaking generally, got away the quickest with their production when shells were very badly wanted. As time went on this adapted plant deteriorated; meanwhile permits for machine-tools had come in, but they were unable to buy new tools, though they knew what they wanted and where their weak places were. Piecework time rates had been set, and by agreement they must not be altered, so that most firms were face to face with the facts that their rates were set, their wages were going up on account of increases, the prices of shells were going down, and they were not allowed to buy new plant in order to improve their methods. That was the experience which many firms had had in the Manchester district. The "time-and-line" system seemed to him the only possible way of starting up some of the new work-jobs such as gunwork—where people had no experience at all to guide them. They themselves had to convert a 15-inch shell plant into a 6-inch gun plant. They could not tell definitely what the job would cost; in fact it needed considerable ingenuity to make the plant do the job at all. Mr. Morgan spoke of grading out firms by an index number,

(Mr. Harold Smith, M.B.E.)
and proposed to allot the supply of labour accordingly. Such grading out of firms should also apply to workers, and the system should work both ways. He was particularly interested in figures for the number of female operators considered possible in gun-work up to 8-inch howitzers. He had been in a number of the large gun-shops in the country, and he could not say that any of them had anywhere near that percentage, not even firms directly under Government management.

Mr. A. E. HOWELL said he had had women working on shells for the last three and a half years. The largest shell they had been engaged upon was the 6-inch, and for two years he worked them in 12-hour shifts, with very little sickness. Later he went on the 4·5-inch shell, and the women did every operation in the shop including the labouring. There was not a man on a machine, and there were only two male tool-setters per shift. In fact, the women were doing the tool-setting, and could perform any operation provided it was a straightforward job, and was mapped out for them; but if they encountered anything that was out of the ordinary, the result was deplorable. His experience was that they were difficult to handle and apparently had, should he say, no conscience. As viewers and examiners they were very good, but he could not agree with a great deal of what had been said in regard to women having a delicacy of touch; it took them all their time to use the horseshoe-gauge properly. Women he found were bad timekeepers, and the only way to deal with them was to give them a week's notice if they stopped off two days.

Reference had been made to a chart for shell-making. There had been one in existence in the Ministry for two years, giving the lowest time for every operation on any known shell produced in England. On the 6-inch shell women were engaged on every operation after rough boring, but it was considered necessary to install small cranes for lifting purposes. In their works women had stood for twelve hours (ten and a half hours actual working time), and in the early days of the war, in 1915, they did this for five months; the conclusion he came to was that, provided the

women were of a suitable physical type, there was not much difficulty in doing the work.

Mr. G. W. Cooke said he would like to give his views on the different operations upon which women were engaged. Taking Lancashire first, the women working at the collieries were very efficient and often better than the men; and on the machines for cleaning coal, and various other appliances, they were better than boys. He had had about twenty-six under his charge. It was true they were more difficult to handle than men, but on inspection work, such as examining screws, threads, bolts, and using micrometers they were equal to the men. In one case he had to call a man to account because a girl engaged on the same class of work was doing twice as much as he was. He (the speaker) saw no reason why the girls in this country should not equal the girls and women in other countries, such as India, French Indo-China, the Philippine Islands and China, where female labour was the rule. Particularly in machine-shops, they were quite equal to the men.

Mr. Ben H. Morgan, replying to the discussion, said that Dr. Hopkinson referred to the heavy work the women were doing in the way of lifting shells, and so forth, and very rightly called attention to the danger involved in such a practice. He agreed that in the operation of machining shells a woman should not be called upon to lift continuously any size of shells over 4·5 inches. Mr. Howell had stated that in his shop women had performed all the work, including lifting, on 6-inch shells after the rough boring, and were engaged for as long as twelve hours a day for seven days a week for quite a long period. That was an undesirable case of employing women, which he would not wish to see repeated in any shop. As a point of interest, it was very seldom a group of women could be found who were capable of standing such strenuous work. On the other hand, there was a great difficulty in employing women on work between 60 and 80 lb. in weight, and from the point of view of economics in shop production, it was doubtful whether women could be economically employed on work between those

(Mr. Ben H. Morgan.)

weights for the reason that, if handling appliances were fitted, a strong woman would prefer to lift the material into the machine herself in order to save time. He had known cases of 60-pounder shell shops, where the pulley-blocks of the handling appliances provided had been tied up away from the machine by the women, because they preferred to handle the forgings themselves, but in the long run it did the women great injury, and the practice ought everywhere to be discouraged.

Dr. Hopkinson expressed the opinion that good welfare conditions were a paying proposition. He (Mr. Morgan) was quite sure that the degree of efficiency in the employment of women would always coincide with the provision of first-class welfare conditions.

Mr. Harold Smith's experience with regard to bad time-keeping of women was in opposition to the accumulated experience of firms throughout the country. The time-keeping records which he analysed some time ago for the Hours of Labour Committee showed that women behaved better in that respect than men, and lost less time both from avoidable and unavoidable causes. Mr. Howell also suggested it was a fallacy to say that women had any delicacy of touch or could do finer work than men. That again was in direct opposition to the experience throughout the country. Women could do extremely fine work and were better adapted to it than men. They became used to the finest limits very rapidly, and could be taught to read instruments quicker than men. That at any rate was his experience.

With regard to points concerning standards, made by Mr. Butterworth and Mr. Harold Smith, both speakers seemed to think that there would be difficulty in applying standards fairly to manufacturers using adapted plant, or to those firms which were under comparatively small contracts, compared with the large firms using highly specialized plant and turning out very large quantities. But while it must be presumed that the standards would conform to conditions with regard to adapted plant, and indeed to other conditions obtaining, the effect would always be to promote the flow of contracts to the most efficient factories.

Mr. Harold Smith also referred to the difficulty of working outside "time-and-line" methods on gunwork which had to be carried out on adapted 15-inch shell plant. But if the contracting department sent out full information and sufficient drawings to enable the plant to be adapted, that together with details of all operations and methods of subdivision would make it possible to get out the cost quite accurately.

Mr. Harold Smith said that the information was not available at that time.

Mr. Morgan replied that this gun-lining work on heavy shell lathes was not a new practice. It was work which had been going on now for some considerable time, but probably Mr. Smith was speaking of an early experience. He quite agreed that where it was an experimental job, the "time-and-line" method was inevitable where the work had to be done very hurriedly, but it was still being employed by various Government departments for products which ought to have been standardized long ago.

Then Mr. Smith referred to the gunwork dilution standards mentioned in detail in his (Mr. Morgan's) Paper. Those standards were based on actual cases, and were less than were being carried out by individual firms. He would be very pleased to give Mr. Smith the actual cases and to arrange for him to visit the firms.

He thought he had covered the points raised in the discussion, but, in concluding, he would like to refer to the question of setting up a Committee of the Institution of Mechanical Engineers to study women's work, its subdivision, and its value in production, and to ascertain how maimed soldiers were to be employed in industry in this country. These were very important questions which affected the organization of every works in the country. Men were now being discharged from the Services in large numbers every month, and they would be a charge upon this country unless steps were taken to train them and introduce them into works. To ascertain their bench and machine

(Mr. Ben H. Morgan.)

value, and to tabulate all the information necessary about appliances and machine adaptation, was, he thought, the work of a technical institution such as the Institution of Mechanical Engineers. The numbers discharged would be considerably greater in the very near future, and these men should not be lost to industry in this country. The Germans, right from the start of this war, set up elaborate training arrangements for discharged men, and as they had been released they had been put on productive work. Practically nothing had been done in this country. There were one or two organizations like the Lord Roberts' Workshops, Roehampton Schools, etc., which were totally inadequate. These men, instead of being a producing element, and living under much happier conditions, would become a charge upon the country if Government departments were left to do the whole of the experimental training and re-training work. He thought it was a great opportunity for such a body as the Institution to take up and study this question now—not to interfere with the machinery of Government or the distribution of these men in any way, or the wages they were to be paid, but to provide the data and information necessary to show what work every type of disabled man could profitably do in industry, and how that work could be carried out in the shops by improvisation of limbs and adaptation of plant.

After the London Meeting at which his Paper was read, he received the following morning a communication from a well-known manufacturer—who desired to remain anonymous—offering to the Institution £1,000 towards the expenses, and he had no doubt that other large sums could be collected if the Institution set up a Committee to investigate the whole subject thoroughly as he thought it deserved to be.

A Vote of Thanks to the Author concluded the proceedings.

Communications.

The President wrote that much had been said about ability and something of the inability of women to perform engineering operations, but very little about the expediency of thus employing them. The last sentences of Miss Monkhouse's Paper were the most important, and they had not received the attention they deserved. The wealth and strength of England depended on the number of her children, the care they received in early life, and their subsequent moral and intellectual training. If, after the war, when the present necessity for employing women to do men's work would be less urgent, they allowed motherhood to be put into competition with 40*s.* a week, he feared the results would be disastrous. While they thanked the women who were helping them to win the war, for their energy and devotion, he thought the worst return they could make them would be to encourage them to undertake men's work; rather their aim should be so to raise men's wages that there should be no need for women to give up their natural functions.

Mr. J. Pollock Brown wrote that, though not able to criticize Miss Monkhouse's Paper, he would like to record his experience and appreciation of about 800 women employed on light class engineering work, including machining on automatic tools, semi-automatic, and capstans, drills, etc., also electrical winding, bench work, riveting and assembling aircraft appliances from stampings, inspection with limit-gauges, etc. The bulk of the women had been placed in separate departments from the men and boys, with educated forewomen and charge-hands, and carefully chosen skilled tutors or supervisors, also a proper supply of suitable tools and jigs. The results had been very satisfactory, and the avoidable time lost was under 2 per cent. Day and night shifts of $8\frac{1}{2}$ hours (actual working) had superseded the 3-shift system with benefits to all concerned.

The advent of women had no doubt forced engineers into "manufacturing" lines which necessitated the use of real skill in

(Mr. J. Pollock Brown.)
designing, planning the work and supplying the necessary shop appliances. Women were not so irresponsible as boys, and could do exceedingly well on repetition work, even of such high order as was necessary in aero-engine parts.

Mr. Morgan's Paper gave food for much thought, as the labour item had always been a most elusive one in estimating, unless payments by results were accepted by the workers. As a reliable standard of shop efficiency should include all indirect charges, the statement of men or women hours would be misleading. One factory through extra equipment and supervision might be able to reduce the woman-hours for certain work, but the total cost might exceed another factory with less face efficiency of woman-hours. Women had undoubtedly won a position in "manufacturing," but only to a limited extent in "making" of engineering products, but the degree of success lay more or less in sympathetic management.

Mr. C. J. BOWEN COOKE, C.B.E., wrote that, with regard to the suggestion of a Committee to study the best way of training discharged soldiers, including maimed * men, the following were definite cases where positions had been found in the Locomotive Department at Crewe for discharged soldiers unable to resume their old occupations: a fitter, formerly employed on locomotive repairs, now having a paralysed arm, is acting as a sanitary attendant; a general labourer, now having an injured arm, is acting as a traverser driver; another general labourer, having lost the right arm above the elbow, is now acting as assistant in Shop Tool Stores.

In one or two cases where men had lost an eye, they had been allowed to resume their old positions, subject to their agreeing to wear suitable goggles for the protection of the remaining eye while at work.

Mr. JAMES F. DRIVER (of The Technical College, Loughborough) wrote that, from his experience, the success of women in munition

* *See* also Colonel Pringle's Report to the Board of Trade, giving schedule of occupations on railways which it was considered could be well performed by men who had been injured in various ways.

work depended almost entirely on the attitude taken up by the employer, foremen, and other skilled workers in the factory. The employer and his foremen were often much alarmed at the prospect of maintaining output whilst skilled youths were being called to the Colours, and their places filled by women, and it said much for the patriotism of all concerned that so much had been accomplished. It was generally conceded that shell-turning and single operation jobs of similar character could be done by women, but few realized that, with suitable training, women could be employed on work requiring far more skill and resourcefulness.

At the Loughborough Instructional Factory, which now formed one of the departments of the Technical College, women had been successfully trained for practically every branch of engineering, from the drawing office as "junior draughtsmen" to aeroplane-engine testing, but the class of work in which they had proved astonishingly successful was gauge-making and precision grinding. This was probably due to the fact that women had infinite patience, and once they realized the degree of accuracy required, could be relied upon to attain this standard. That this theory was true might be shown by the fact that many women had been trained and placed with various firms of gauge-makers for such work as lapping and finishing flat, cylindrical, and screw-gauges, and to such women, the question of working within a limit of two ten-thousandths of an inch, presented no insuperable difficulty. The same remarks applied to the employment of women on light woodwork, such as aeroplane ribs, wings, etc. With extended training, some women made very fair tool-setters on capstan and other lathes, but as the value of a tool-setter depended largely upon the number of years which he had been engaged in engineering, and therefore the amount of experience he could bring to bear on any problem, it was obvious that women could not be expected to compete with engineers in this class of work, but it was only fair to remember that these remarks would apply with equal force to men dilutees.

Miss G. T. LEWIS wrote that having had some experience during the war in handling and instructing woman labour at bench-fitting,

(Miss G. T. Lewis.)

she thought that the views of a woman who had taken up engineering work during the war might be of interest to the Institution. During the year in which she had charge of this fitting-shop, some 200 women passed through her hands, and of these quite 25 per cent showed distinct mechanical ability, the latent instinct for this class of work making itself apparent in many cases within a fortnight, when the right kind of instruction was available.

An important part of the intensive training to which women had been subjected on munition work, was the acquisition of the trade vocabulary, for it must be remembered that the training period had been cut very short, and that facilities, extending over several months in the case of boys and apprentices, had been thereby curtailed. The girl trained had to learn the meanings of many strange words, such as the *gauge* of sheet-metal for its thickness, a *radius* used for a curved surface, *square* for at right-angles, and so on. What lad at the same age would know a gore from a gusset, a hemmed-and-felled seam from a tuck, or the meaning of terms like bias, basting, or whip-stitching? Not only was there the terminology of the operations to be learned, but there were names of tools and appliances as well as those of the parts of the work to be mastered, and, in the case of more advanced girls, it was necessary that they should learn to read drawings, to mark off work, and to use the micrometer and other measuring appliances.

The lad who was to become an engineer started his apprenticeship, say, at the age of fourteen, and for five years thought and worked for nothing else than engineering, apart from a reasonable interest in games and sports. These years from fourteen to nineteen were the acquisitive years, when the brain was most receptive. For the girl, the conditions for the same period had been quite different; she had been engaged perhaps in an office, writing shorthand or typewriting, or both, or doing monotonous household work such as sewing, cleaning, or cooking, and at the end of the day's work she probably had to help her mother with the younger members of the family. If this preliminary training of the material from which our women munition producers had been drawn, had left them with

so high a power of adaptability to the new conditions of work, was it not reasonable to expect that girls, if given the same facilities as boys, might become really efficient engineers?

It was true that the present system of training made efficient producers in specialized and rather narrow fields of work, and it was not to be expected that women could attain to all-round knowledge by any short cut, such as might be assumed to exist from the successful results obtained by the specially directed training of to-day. To force the pace so as to acquire the necessary all-round knowledge of the professional engineer in a much reduced time, would probably require so large a specialized staff of instructors as to be prohibitive, and the strain on the learners would prove too heavy for any but the strongest; nevertheless, it appeared from the progress made by women as compared with lads who had spent two or three years in the shops, that the new methods of training might be applied to boys with equal advantage.

The most satisfactory results in training women had been obtained so far by instruction under sympathetic male charge-hands; it was hardly possible, even at present, to state whether better results could not have been obtained by women instructors, but, of course, such at present were extremely rare. On the other hand, it was certain, and was borne out by the experience of all who had visited many factories, that the most efficient shops, from the point of view of production from women labour, were those supervised by women, and where a broad-minded welfare superintendent was in charge, for whom the girls would feel full respect and confidence, and to whom they would turn without hesitation in trouble.

The successful employment of women was also dependent on local or shop organization, which required modification from the conditions which obtained when men only were employed. These were not merely the provision of stools for seating and of short breaks during the working hours for rest, but more important matters such as the choice and powers of the charge-hands, the lay-out of the shop and broad questions of principle such as the desirability of separating the women's shops entirely or as much as

possible from the men's. Much better production was obtained when the number of women in any individual shop exceeded the number of men, and in cases where trade prejudices were feared, it was often better that the women's work be carried out in an entirely separate building.

The broad question of whether women could enter the engineering profession in the future could not be answered till further experience was available of women whose engineering education had been acquired under conditions parallel to those prevailing for men. Given equal advantages, was it not possible that women, who had already made their mark as artists, musicians, and doctors, as architects, surveyors and in business, might attain to positions of eminence and responsibility in the engineering profession?

Mr. DAVID A. SHERET wrote that he considered it a bold step for any woman to pose as a judge in engineering products at the present time. He most thoroughly appreciated what the women had done, yet the use of women's best work had not been judged in a clear and unbiased way. It was quite true that the skilled men had to do the technical training of the women, and to sectionalize their work, etc. (page 214), but much ill-feeling was created because the wages received by the women were out of proportion to the earnings of the skilled mechanics; and a little further on in the Paper Miss Monkhouse stated that in the hands of the skilled men was "largely the power to oppose and retard all progress by women on skilled work." He (Mr. Sheret) did not know to what skilled work the Author referred, as, although he had visited many munition works, he had found women engaged mostly on machines or on other work that in no degree could be qualified as "skilled work." It was usually admitted by most women students that they preferred a man professor to a woman, although the teaching profession was particularly adapted to women with broader views. The present time was not a favourable one for judging what possible claim a woman could put forward to permanent usefulness in engineering work especially applied to shop operations, but there could be no gainsaying that she could and would prove herself

useful in engineering, or chemical laboratories, or in the scientific departments, where thorough knowledge of mathematics was needed. Miss Monkhouse seemed to think that Utopian conditions would be arrived at if women were appointed to engage labour, and that engineering administrative powers could be gained in a few months which had taken men years with diligent effort to acquire.

Mr. W. W. H. Warneford wrote in reference to the employment of discharged soldiers, mentioned by Mr. Morgan (page 257). In the Wagon Department of the London and North Western Railway at Earlestown there were very few openings which would afford suitable work for men who unfortunately had been crippled. With respect to the actual repairing of wagons, owing to the amount of lifting and climbing that had to be done, there was very little that a man could do unless he was only slightly injured. He would suggest, however, that fitters, turners, millwrights, joiners, carpenters, and the like, who were unable to perform light work in connexion with their respective trades, would be very suitable as charge-hands for gangs of loaders or lifters, or over stores-countermen; and, according to the nature of their injuries, they could work on suitable machines connected with their trades which were at present operated by mechanics.

Labourers, in accordance with the extent of their injuries, could fill positions as watchmen, gatemen, patrol men, and closet attendants, and could work machines such as drilling, slotting, and shaping, and do any job which was now done by handy men sitting down. They could also be employed on rough painting, tarring, touching up, and should make suitable men for stores counters, sweepers-up, and cook-house attendants.

Mr. Ben H. Morgan wrote, concerning an inquiry for details respecting his proposed method of grading, referred to in his Paper (page 249), that it was necessary to remember he had suggested that for every industry two standards should be established, namely:—

(Mr. Ben H. Morgan.)

(1) *Labour Efficiency Standard*, which shall be a number directly proportional to output and inversely proportional to total employees engaged on that product, including proportion of management, etc. (e.g., pieces per 10 man-hours).

(2) *Dilution Standard*, which shall be a number equal to

$$\frac{\text{Women + discharged unskilled soldiers}}{\text{Total number of employees.}}$$

To arrive at the *Grading* of a firm, in so far as labour is concerned, the percentage of the labour efficiency standard attained by the firm is multiplied by the percentage of the standard dilution attained by the firm, and the product is the "figure of merit," or grading number. *Example :—*

Suppose Labour Efficiency Standard for 4·5-inch shells is 9·2 (shells per employee per week), and the firm have an efficiency of 8·6 (shells per employee per week). The percentage labour efficiency is therefore $\frac{8{\cdot}6}{9{\cdot}2} = 93{\cdot}5$. Suppose that the Dilution Standard for 4·5-inch shells is 80 per cent. and the actual dilution is 68 per cent, then the dilution efficiency is $\frac{68}{80} = 85$ per cent.

The figure of merit, or grading number is therefore 93·5 per cent × 85 per cent = 79·5.

In the case of a firm manufacturing different products, the arithmetical mean of the percentages of the labour efficiency standards and of the dilution efficiency standards is to be taken in calculating the grading number of the firm. *Example :—*

A firm is making three products, A, B, and C. The labour efficiencies on the three products are 84 per cent, 76 per cent and 89 per cent of the respective standards. The dilution efficiencies are 31 per cent, 96 per cent, and 56 per cent of the respective standards. The grading is calculated as follows:—

$$\text{(Labour)} \quad . \quad . \quad . \quad \frac{84 + 76 + 89}{3} = \frac{249}{3} = 83.$$

$$\text{(Dilution)} \quad . \quad . \quad . \quad \frac{31 + 96 + 56}{3} = \frac{183}{3} = 61.$$

83 per cent × 61 per cent = 50·63 per cent.

Therefore the grading of the firm is 50·63.

The Institution of Mechanical Engineers.

PROCEEDINGS.

May 1918.

An Ordinary General Meeting was held at The Institution of Civil Engineers, London, on Friday, 3rd May 1918, at Six o'clock p.m.; Michael Longridge, Esq., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following eighty-five Candidates had been duly elected:—

MEMBERS.

Atchison, Charles Claremont,	Bristol.
Berry, William Edgar,	Manchester.
Booth, James Wilson,	Burnham-on-Crouch.
Broughall, Edward Henry,	Coventry.
Daubeny, Edward Cyprian,	Kurduwadi.
Dickson, William Martin,	Trinidad.
Dixon, Frederic John,	Birmingham.
Douglas, John Thomas,	Yeovil.
Fletcher, Thomas William,	Warrington.
Glaser, Herbert,	London.
Holman-Hunt, Hilary Lushington, C.I.E.,	Burma.
Restler, James Douglas Kendall, Lieut.-Com., R.N.V.R.,	London.
Tait, Edward Berry,	Colchester.
Troup, John Dawson, Lieut., R.F.C.,	Reading.

ASSOCIATE MEMBERS.

*Adams, Dudley, Captain, R.G.A.,	London.
Anderson, Fred Garbutt,	Manchester.
Appleton, Sydney,	Ottawa.
Banks, Samuel James,	Lyons.
Beacham, Thomas Edward, Lieut., A.O.D.,	Woolwich.
Blaikie, William Scott,	Chapel-en-le-Frith.
Boyd, John,	Goole.
Bramwell, Ernest Charles,	Oxford.
Butler, Wilfred,	Manchester.
Butterworth, Joseph Alexander,	Loughborough.
Calisch, Lionel,	London.
Cameron, Alexander, 2nd Lieut., R.E.,	London.
Carrington, Herbert,	Manchester.
Cassie, George John,	London.
Chaloner, John Leopold, 2nd Lieut., R.E.,	London.
Charnock, William Cowan,	Manchester.
Collins, Herbert,	London.
Coombs, Robert Lennox, Captain, R.F.A.,	London.
Crosby, Robert,	London.
Dancaster, Henry William,	Jarrow-on-Tyne.
Devine, Denis,	Coatbridge.
Drayson, Donald,	Stevenage.
Driver, James Frederick,	Loughborough.
Eady, Reginald George,	Lincoln.
Ellison, John Maurice, Lieut., R.F.A.,	London.
Fearn, John,	Birmingham.
Fildes, John Henry Storey,	London.
Fozard, Harry Edwin,	Manchester.
Greenwood, Rowland, R.N.A.S.,	Halifax.
Hanton, John Ramsey,	Hawick.
Hodgson, William, Major, R.G.A.,	B.E.F.
Jones, Frederick Tobias,	Birmingham.
Kempe, Irwin Trevanion, Capt., A.S.C., M.T.,	B.E.F.
Knight, Royston Engleheart, M.C., Major, R.E.,	B.E.F.
Lawrence, John Charles Ogg,	London.
Luckett, Arthur George,	Woolwich.
Maxted, Frederic Reginald,	Liverpool.
Menkens, Cyril,	Harwich.
Meredith, Percy Hamilton,	Widnes.

* Killed in action on 21st March 1918, before his election could be completed.

Miller, Archibald Sidney,	Pembrey.
Noble, Guy, Lieut., A.O.D.,	Dover.
Novelli, Marino,	Alexandria.
Paulin, George Henry,	Rugby.
Perry, Edgar William Frank,	Manchester.
Pirie, Alexander Herbert,	London.
Playne, Alfred Charles, Eng.-Lieut., R.N.R.,	Stroud, Glos.
Quicke, Joseph Henry,	Hainault, Essex.
Reddy, Frederick Harry,	London.
Rhodes, Joseph,	Khartoum.
Robson, John,	London.
Scott, David Pyott,	Norwich.
Spence, John William,	Birmingham.
Stack, William Auchinleck, Captain,	Burton-on-Trent.
Stork, Sidney George,	Rochester.
Tanner, William Selby, Jun.,	London.
Taylor, Benjamin,	Manchester.
Vowles, William Hugh Pembroke,	London.
Warren, Charles Thomas,	London.
Webster, Nicol James,	London.
Williams, Victor Stanley,	Alperton.
Wilson, Percy Harold, Captain, R.E.,	London.

ASSOCIATES.

Garrett, Charles Alfred Blythe,	Ashford, Kent.
Hawes, Bertram Lowth,	S. Farnborough.
Nutton, Harry,	London.
Skerrett, Henry Norton,	Birmingham.

GRADUATES.

Davey, Thomas Farrance,	London.
Higgs, Percival John,	Devonport.
Moore, John Eric,	Leeds.
Reed, Frederick Horace,	London.
Rogerson, Harold,	Southampton.
Stanley, Ernest,	Grimsby.
Wiltshire, Geoffrey Hall,	Bath.

The President announced that the following six Transferences had been made by the Council:—

Associate Members to Members.

BROCKLEHURST, HERBERT CECIL, . .	New York.
CRITCHLEY, HERBERT LAWSON, M.B.E., .	London.
DIGBY, CLIFFORD, ...	Lincoln.
LOCKWOOD-BUNCE, THOMAS, M.B.E., . .	London.
QUELCH, ARTHUR TEMPLE, . . .	London.
WALKER, WILLIAM PETO, ...	London.

The PRESIDENT said that the cards announcing the Meeting had stated that the discussion would be continued that night of Miss Monkhouse's Paper, and that another Paper would be read if time permitted. He had to apologize for having been unable to give the title of the second Paper; the reason was that, when the notices were sent out, it was not known whether the Ministry of Munitions would allow Mr. Morgan's Paper to be read. Happily, their consent had been obtained, and Mr. Morgan's Paper would be read, and the two Papers discussed.

The following Paper was then read and discussed jointly with that by Miss O. E. MONKHOUSE, M.B.E., on "The Employment of Women in Munition Factories," which had been discussed at the March Meeting:—

> "The efficient utilization of Labour in Engineering Factories: with special reference to Women's Work"; by BEN H. MORGAN, of London.

The PRESIDENT announced that the Papers by Miss Monkhouse and Mr. Morgan would be read and discussed in Birmingham on 9th May, and in Manchester on 10th May.

He would now ask them to pass a Vote of Thanks to The Institution of Civil Engineers for lending them their rooms during the past Session. The next Meeting would not take place until October, and he hoped that by that time they might be in sight of getting into their own building again. In the meantime they had

had hospitality given to them in large measure by The Institution of Civil Engineers, to whom they owed their most hearty thanks.

The Vote of Thanks was passed by acclamation.

The Meeting terminated at Half-past Seven o'clock. The attendance was 98 Members and 110 Visitors.

At the close of the Meeting The President exhibited and explained the use of a portable apparatus for determining the Hardness of Metals by an impact Brinell ball-test, which he had seen at the Munitions Inventions Department, and mentioned that a Note by Mr. C. J. Bowen Cooke, C.B.E., *Member*, describing some tests made at Crewe Works would be printed in the Proceedings (*see* page 331).

The Papers by Miss Monkhouse and Mr. Morgan were further discussed, as follows:—

Birmingham, at the Medical Lecture Theatre of the University, Edmund Street, on Thursday, 9th May 1918. Chairman: Sir Gerard A. Muntz, Bart., *Member of Council.*

Manchester, at The Engineers' Club, Albert Square, on Friday, 10th May 1918. Chairman: Dr. Edward Hopkinson, *Member of Council.*

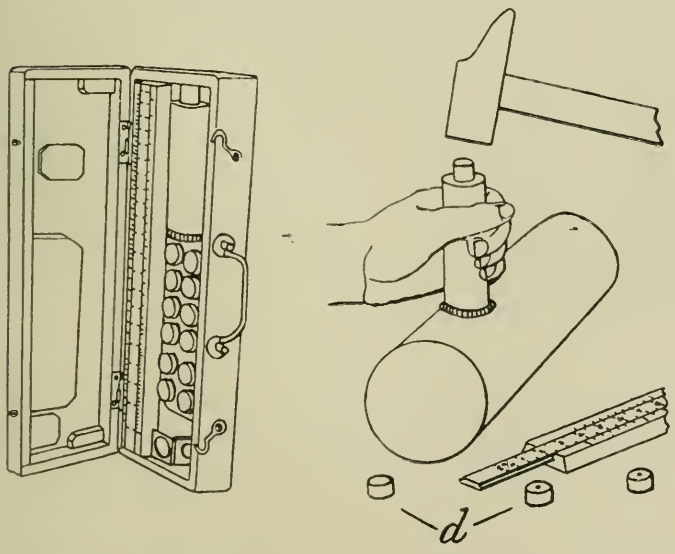
TESTING HARDNESS OF METALS BY THE BOYELLE-MORIN APPARATUS.

Communicated by C. J. BOWEN COOKE, C.B.E., *Member*, Chief Mechanical Engineer, London and North Western Railway, Crewe.

[*Selected for Publication only.*]

The Boyelle-Morin apparatus, here shown, is intended to give the same results as the well known Brinell Hardness Testing

Outfit and Method of making a Test.

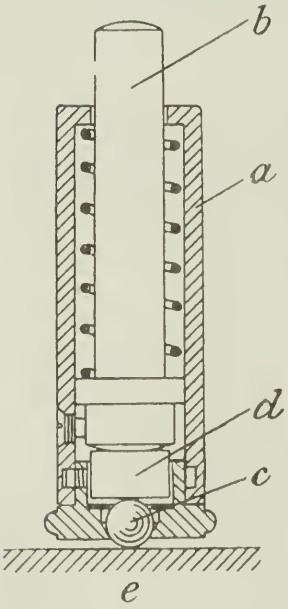


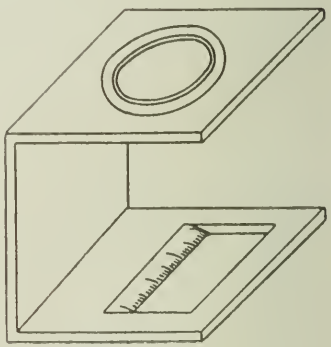
Machine, but unlike the latter it is portable and can be used upon castings or forgings, where the Brinell Machine cannot be employed.

[The I.Mech.E.]

It consists of a tube *a* carrying a hardened steel ball *c*, and a rod *b* enlarged at the lower end to slide freely in *a*. Interposed between the lower end of *b* and the ball *c* is a cylinder or cube *d* cut from a bar whose hardness has been determined in a 3,000-kilogram Brinell Machine. The apparatus must be held vertically with the ball *c* resting on the surface *e* to be tested, and the top of the rod *b* struck sharply with a hammer causing the ball to indent *d* and *e*.

10 *mm. Ball and Microscope to read Diameter Imprints.*





The diameters *d* and *c* of the indentations are measured by the scale and magnifying glass shown, and the corresponding hardness numbers are read off on the specially graduated slide-rule also shown (page 331).

Comparative tests made at Crewe with the apparatus and a 3,000-kilogram Brinell Machine on 18 specimens of steel ranging from 0·15 per cent. to 0·64 per cent. carbon, from 29 tons per square inch to 58 tons per square inch in tensile strength, and from

121 to 255 hardness by the Brinell Machine gave hardness numbers differing on the average by 2·4 per cent. of the Brinell Numbers. In three cases the difference was between 6 and 7 per cent., but in six it was less than 1 per cent.

The apparatus may therefore be considered as a workshop tool giving results of sufficient accuracy for workshop testing of many of the steels in ordinary use. Whether the concordance would be as satisfactory with harder steels is questionable.

The apparatus would be more reliable if some provision were made for insuring that the rod *b* is truly vertical when it is struck.

Note by the Secretary.—A portable Brinell Meter, somewhat similar to the instrument described in the above Communication, has been used in America and various other countries. The complete outfit weighs only 6½ lb., including six standard bars 6 inches long, having four surfaces, sufficient for making 100 tests.

A LAW GOVERNING THE RESISTANCE TO PENETRATION OF METALS WHEN TESTED BY IMPACT WITH A 10 MM. STEEL BALL; AND A NEW HARDNESS SCALE IN ENERGY UNITS.*

By Professor C. A. EDWARDS, D.Sc., of the University of Manchester, and F. W. WILLIS, B.Sc. (Tech.).

Some time ago it was necessary for one of the Authors to select a method of determining the hardness of metals at elevated temperatures. For this purpose it was considered essential that whatever method might be finally adopted, it should be capable of giving results which would be quantitatively comparable with one of the recognized methods in use for making similar determination at the ordinary atmospheric temperatures, and would also give satisfactory results up to temperatures as high as 900° C. (1,652° F.). Needless to say, these conditions make it evident that the Brinell method of maintaining a definite load, for a certain time, on a hard ball pressing into the surface of the specimen, could not be expected to provide really reliable data, and the Shore Scleroscopic instrument could not be satisfactorily applied to work of this kind. So far as the Brinell method is concerned, the chief objections in this respect

* A Prize of £25 has been awarded for this Paper from the Sir Robert Hadfield Prize Fund, by the Council. It is intended to discuss the Paper with another one on the same subject next Session.

are: (1) It is extremely difficult to ascertain how long the load should be applied in order to get results that would be comparable with metals of varying hardness, or, what is practically the same thing, with any one metal at different temperatures; (2) There is no ready means of deciding upon the minimum load that should be used in order to obtain hardness-numbers that would have the same significance for materials possessing different hardness; and (3) At comparatively high temperatures the ball itself would become annealed, and in consequence the results might prove to be of very little value.

It was thought that these troublesome features could be eliminated by using an impact device, whereby a known amount of energy could be imparted to a hammer, and the blow transmitted through a hardened 10 mm. ball on to the surface of the specimen under test. The hardness of the material then being estimated in the usual way by measuring the diameter of the impression produced. For this purpose it was, therefore, necessary to design a new instrument which would need to be carefully calibrated with a wide range of metals at the ordinary atmospheric temperatures against the corresponding results obtained by the static method.

As regards the simple comparison of the methods, no real difficulties were anticipated, nor, in fact, were any encountered, but before the experiments had been carried very far, it became evident that the work should be enlarged to an extensive examination of the hardness of metals under dynamic tests. This has now been done to a very considerable amount, and whilst all the interesting side issues relating to this question have not as yet been thoroughly elucidated, the results obtained are so striking, as to warrant their immediate publication. This was considered to be desirable both for the purpose of announcing the results themselves and, what is perhaps of greater importance, of drawing attention to the possibility of usefully extending the application of making impact hardness determinations. One great advantage which has been discovered in this method, which is not apparently shared by any of those that have been adopted up to the present, is that it can be used as an "absolute scale for measuring the resistance offered by metals to

their penetration by other rigid bodies." Further, it appears to possess all the advantages of the Brinell method, and can be made to give the information obtained from the Scleroscope, with a single apparatus which is extremely simple, easy to manipulate, and quite inexpensive.

It cannot be claimed that the idea of utilizing the impact principle is new, because Shore's Scleroscope is based upon this, and it has also been applied by other investigators. Brinell in his original Paper refers to some impact hardness tests from which he arrived at the following conclusions:—"That in cases of large specimens, it might be found impossible to place them in the testing machine, if static pressures, gradually applied to the ball, are to be used. In such cases, however, there is as a rule no difficulty in making impressions of the ball in the specimens by applying dynamic pressures (impact)." He made experiments for the purpose of determining the relation between impact ball-tests and the ordinary static ball-tests. "The experiments were carried out in the following manner; first, an ordinary ball-test (static load 3,000 kg.) was made, and the diameter of the impression was measured; secondly, by repeated trials, the height through which a weight of 5 kg. must fall so as to make a similar impression with a 10 mm. ball was determined. This height was found to be 450 mm. Tests made with iron, containing 0·10 per cent. of carbon, showed that energy of impact amounting to about 2·25 kilogram-metres, corresponds to a static load of 3,000 kg. gradually applied. One might have expected that this relation would also hold good for other percentages of carbon, but experiments show that this is not the case. On the contrary, it appears that the harder the metal is, the greater is the difference between the hardness-number determined by using a load gradually applied and that determined by impact. The difference is this, that the hardness-numbers found by impact tests are higher than those found by static ball-tests." To get the hardness-number for the impact tests, Brinell assumed that the effect on the ball of the weight of 5 kg. falling through 450 mm. was equal to a gradually applied load of 3,000 kg. The number was found in the same way

in each case. The fact that under these conditions the hardness numbers obtained by the two methods do not agree, might appear to be a definite obstacle to the application of the impact test.

Mr. J. O. Roos, has made a study of this subject, and from mathematical considerations he came to the conclusion that, if the energy of impact Q, and the pressure P, are kept the same when making tests by the two methods on different metals, one may expect to find that:—

$$\frac{H_s^2}{H} = \text{a constant.}$$

H_s = Impact hardness.

H = Brinell hardness.

He made experiments, to test this view, with a series of carbon steels with carbon content varying from 0·1 to 1·0 per cent. The data obtained, when treated in the manner mentioned above, showed that the constant increased with the percentage of carbon. With from 0·10 to 0·20 per cent. of carbon it was 110–112; for 0·30 to 0·60 per cent. of carbon 115–118, and for above 0·60 it varied irregularly between 113 and 135. These variations are much too serious to permit of the impact method being extensively used in the case of metals of unknown and possibly widely differing hardnesses. There would be very little hope for the impact method if a better means could not be found for converting the indentations produced into terms of the more firmly established method such as the Brinell.

Description of Testing Apparatus.—It was this aspect of the problem which one of the present Authors wished finally to settle before proceeding with the other investigations it was proposed to make. The more essential features for the apparatus which was first used were specified to, and these were then embodied in the instrument which was designed by Mr. Gerrard, M.Sc. In broad outline, this consisted of a block of steel weighing exactly 21 lb. which could be released by a mechanical device and allowed to drop 3 inches to the surface of the specimen under test. The specimen itself was very rigidly held in a heavy steel base, and when

TABLE 1.

Description of Sample.	Diameter of Impression in Millimetres.								
	Impact Tests.			Brinell Tests.					
				Load in Kg.					
	(1)	(2)	(3)	500	1,000	1,500	2,000	2,500	3,000
Aluminium	6·35	6·25	—	5·55	7·27	8·50	—	—	—
Copper	4·48	4·60	4·55	2·82	3·85	4·70	5·38	6·01	6·50
Duralumin	4·03	4·10	4·10	2·42	3·15	3·89	4·40	4·90	5·30
Mild Steel	3·93	3·91	3·90	2·40	3·20	3·81	4·36	4·80	5·40
Nickel-Chromium, Air-Hardened	3·30	3·30	3·30	1·90	2·50	3·00	3·40	3·70	4·08
Annealed High-Speed Tool Steel	3·25	3·30	3·32	2·00	2·52	3·00	3·40	3·82	4·10
Valve Steel	3·16	3·20	3·20	1·80	2·40	2·82	3·20	3·55	3·85
Medium Carbon Steel	3·10	3·12	3·14	1.71	2·30	2·71	3·11	3·45	3·71
Nickel-Chromium, Oil-Hardened	2·60	2·60	2·60	1·55	1·90	2·20	2·45	2·71	2·90
Hardened High-Speed Tool Steel	2·30	2·35	2·35	—	—	2·00	2·10	2·38	2·50

experiments were being made, the whole arrangement was carefully bedded on a massive steel marking-out table. The energy of the blow produced by the falling weight was imparted to the surface of the specimen through a hardened steel ball (10 mm. diam.) firmly fixed to the weight. The impact energy was the same in all cases, namely 63 inch-lb. The results for ten different samples are given in Table 1 (page 339), along with the corresponding data for Brinell's method with varying loads.

These figures as they stand do not appear to indicate that there is any definite relation between the two kinds of test. They do, however, show that as the hardness of the metal increases, the

TABLE 2.

Material.	Impact H_s.	Brinell H.	$\frac{H_s^2}{H}$.
Copper	174	81	373·8
Duralumin	217	124	379·9
Mild Steel	241	125	464·6
Nickel-Chromium Steel, Air-Hardened .	340	213	542·7
Annealed High-Speed Tool Steel . .	340	206	561·0
Valve Steel	364	245	540·8
Medium Carbon Steel	377	260	546·6
Nickel-Chromium Steel, Oil-Hardened .	555	422	729·0
Hardened High-Speed Tool Steel . .	700	600	861·6

difference between the size of indent becomes less. As previously stated, according to the theory of Roos, the ratio of $\frac{H_s^2}{H}$, should remain constant, but as will be seen in column 3, Table 2, this is very far from being correct. Perhaps the most important reason for the marked disparity in the ratios thus obtained is, that Roos in making his calculations appears to have assumed that the amount of energy absorbed by the samples, with a fixed energy of impact, would be the same for metals possessing different hardnesses, but as will be seen later this is not so.

A much more convenient and satisfactory way of comparing the two methods is to plot the indentations produced at a standard load

for Brinell against the corresponding figures for impact. This has been done in Fig. 1, where it will be observed that all the points lie exceedingly close to a perfectly straight line, thus showing that the indentations formed by one method bear a more or less definite relation to those produced by the other. This fact becomes even

Fig. 1.—*Brinell Indents with Load of 3,000 kg. and Impact Indents 63 inch-lb.*

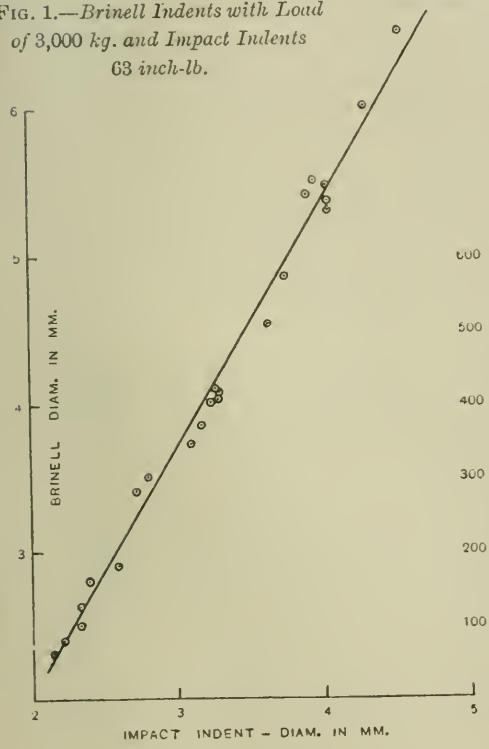
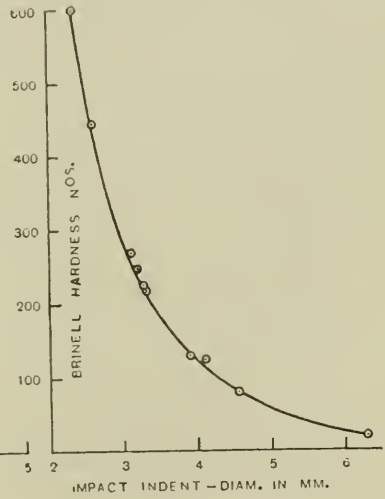


Fig. 2.—*Brinell Hardness Nos. and Impact Diameters with 63 inch-lb. Impact.*



more evident on examining the diagram in Fig. 2. In this case the maximum Brinell hardness-numbers obtained by any load up to 3,000 kg. are plotted against the diameters of the impressions formed by an impact of 63 inch-lb. The equation for this curve is

$$H = \frac{7582}{d^3},$$

where H is the maximum Brinell number obtained with pressures not exceeding 3,000 kg. and d is the diameter of the impact indent. Hence, it is quite an easy matter to use the impact method, at least within the limits of the conditions that prevailed in the experiments described above, and calculate the exact hardness-number that would be obtained with the same metal if it were tested under a gradually applied load.

At this stage of the investigation the following questions naturally arose:—(1) Can the above equation be used if varying impact energies are applied? (2) Is the diameter of the indent governed entirely by the energy of impact, and independent of the velocity of the falling weight? (3) Is the amount of friction between the guides and the weight sufficient seriously to interfere with the extent to which the ball penetrates the metal, and (4) Is this method of testing likely to provide more reliable results and a more accurate hardness scale than the methods devised by Brinell and Shore?

Before those questions can be answered it will be necessary, at least briefly, to discuss some of the more serious defects which exist with Brinell's method, and also with the impact method as it is embodied in the Shore Scleroscope.

Methods of gradually Applied Load.—It is well known that the time during which the load is kept upon a specimen has a marked influence upon the resulting hardness-number. This has been recognized for some time, but it has been very clearly demonstrated in an interesting Paper by W. N. Thomas.* In spite of this, it is not known how this time-factor varies with metals of different hardness, though it probably becomes very small as the hardness gets greater than about 400 Brinell. This defect is to some extent neutralized, but it is certainly not removed, by maintaining the load for one definite time for all experiments.

The hardness-number is taken as the figure obtained by dividing the spherical surface area of the indent in mm^2 into the load applied. Whenever it is possible, for purposes of comparison

* Journal, Iron and Steel Institute, 1916, Vol. I, page 255.

a standard load of 3,000 kg. is used. In consequence of this, it follows that the degree of deformation produced varies, within very wide limits, with the metal which is being tested; and since different metals, or the same metals in different conditions, are not hardened to the same extent by cold deformation, it follows that the values obtained in this way are not strictly comparable. That the practice of making these tests under a standard load presents real and not imaginary difficulties will be recognized on examining the hardness-numbers for different loads given in Table 3. If the

TABLE 3.

Description of Sample.	Brinell Hardness Numbers. Load in Kg.					
	300	1,000	1,500	2,000	2,500	3,000
Aluminium	19	20	17	—	—	—
Copper	79	83	82	81	80	80
Duralumin	108	125	121	125	124	126
Mild Steel	109	121	127	128	130	121
Nickel-Chromium Steel, Air-Hardened	175	200	207	214	224	221
Annealed High-Speed Tool Steel	157	198	207	214	211	217
Valve Steel	194	218	231	242	244	248
Medium Carbon Steel	219	238	256	257	259	268
Nickel-Chromium Steel, Oil-Hardened	264	350	390	418	427	444
Hardened High-Speed Tool Steel	—	—	472	570	548	600

method were perfect, the numbers would be the same no matter what load were used. The figures in Table 3 are calculated from the indents in Table 1.

Broadly speaking these discrepancies may be briefly summarized as follows: as the hardness of the metal increases, the load it is necessary to apply, in order to reach a standard maximum value for the hardness-number, must be raised. This may be expressed in another way; with increasing hardness there is a tendency for the Brinell method to give a low measure of the true hardness of metals. This becomes evident with samples having a Brinell number

of above, say, 250, and is particularly marked when they are over 400. In view of this fact the numbers for soft metals are not really comparable with those for hard samples when the observations are made with the same load, and it is almost impossible to say what load should be used in order to get the truest value for the very hard substances such as hardened tool-steels. Perhaps a better way of making the determinations with gradually applied loads would be to produce a standard degree of deformation in all cases, and express the hardness as the load required to give the specified amount of displacement.

Shore's Scleroscope.—One objection to this instrument, which may be unavoidable from the point of view of the application of the rebound principle to quick commercial testing, is the fact that the hammer is dropped from a fixed height, and consequently the energy of impact is the same whatever may be the hardness of the material tested. This inevitably leads to the serious drawback that the puncture or indent made on impact varies quite appreciably with different materials. At first sight, this may not appear to be a real obstacle, but after a little careful consideration its true significance will become apparent. The principle of the Scleroscope is based on the idea that the height of rebound after indentation is a measure of the hardness of the substance tested. There are good reasons for believing that within certain ranges this is true, but it is extremely important to remember that the height of the rebound can only be regarded as a true indication of the hardness of dissimilar materials when the energy of impact is so adjusted that exactly the same amount of deformation is produced in each case. This might conceivably be achieved in the following manner: by keeping the weight the same in each case and changing the height of fall to cause the hammer to indent the various materials to the same extent, when the hardness could be expressed as the rebound in percentage height of fall. Another way would be to measure the indentation made with the present apparatus, and if the arithmetical relations were known, to calculate the energy of impact that would be required to give a certain standard indent.

Modified form of Apparatus.—After completing the results, which have already been described, with the apparatus that was first constructed, it was decided that in order to make an adequate investigation of the advantages and disadvantages of the impact method it would be necessary to reconstruct the earlier instrument.

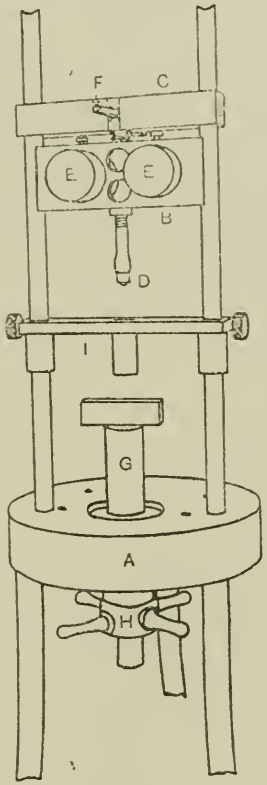


Fig. 3.

Impact Device for transmitting a known amount of Energy through a Hardened 10 *mm. Ball to Surfaces under Test.*

From the experience gained whilst making the preliminary experiments, it was obvious that a much simpler apparatus could be used which would, at the same time, be capable of giving almost any desired degree of impact energy on the horizontal surface of the specimen under test. The proposed modifications were suggested to

Mr. Gerrard, and he embodied them in the apparatus which is illustrated in Fig. 3. This consists of a heavy base A, which is supported by three legs that are firmly screwed into it. On the upper side of the base are tightly fixed two upright rods of steel which act as guides for the weight B which slides very loosely between them The beam or cross-piece C serves to support the weight and regulate the height from which it is allowed to fall. This beam can slide up and down on the guides. Its position can be accurately adjusted by means of two balls in spring sockets engaging in groves exactly one inch apart, on the inner sides of the guides. The highest position of the beam permits the weight to fall 21 inches measured from the lowest part of the ball, fixed at D, to the surface of the specimen. As shown in Fig. 3, the weight was exactly 3·5 lb., but by removing the two cylinders EE of duralumin the weight was 1·75 lb. If instead of duralumin two steel cylinders were used, the total weight was 7 lb. Hence with this simple arrangement it was possible to arrange for any degree of impact energy between $1\frac{3}{4}$ to 147 inch-lb. The weight was released from its hanging position by pressing the handle F. Care was always taken to keep the guides well smeared with vaseline to allow the weight perfect freedom to fall, with the minimum amount of friction. That the friction was exceedingly small and insufficient to interfere with the value of the results is manifest from the fact that practically the same indentations were produced even when the weight was dropped from different heights, providing the same impact energy was applied; for example, the same results were obtained with a weight of $3\frac{1}{2}$ lb. falling 20 inches as for a 7 lb. weight falling 10 inches.

Since the height from which the weight fell was determined by the fixed position of the groves, the exact distance of the fall when specimens of varying thickness were being tested had to be regulated by other means. This was done by adjusting the height of the dummy G, on which the specimen rested, by means of the screw H. Specimens were not allowed to rest loosely on the dummy, because energy might possibly have been dissipated in this way. The samples were, therefore, rigidly held down by

means of the holder I, by sliding it on the guides and tightly screwing it on the specimen. When the weight is released, the striker on the lower side passes freely through a hole in the holder and hits the specimen. Before making any experiments the apparatus was carefully placed, so as to ensure that the guides were in a perfectly vertical position, on a thickly concreted ground floor. The instrument was in such a position during all the experiments which have been made.

Effect of Second Impact resulting from Rebound.—After the impact, the hammer rebounded to a considerable extent depending upon the metal which was being tested and upon the original height from which the hammer fell. Whilst in most cases it was a comparatively easy matter to catch the hammer during this rebound and thus prevent the specimen being struck a second time, in a good many instances this could not be done. The difficulty of preventing this second impact was very pronounced when the initial height of the weight was below about 6 inches.

In view of this, a large number of observations were made to determine what influence, if any, the secondary impact had upon the diameter of the indentation. It was found that if with the second impact, the ball fell in exactly the same indent formed by the first, it had no influence whatever upon the diameter of the impression. If, however, the second blow did not fall upon the same position as the first, a second but much smaller impression was made which distorted one side of the first indent. This distortion did not appreciably interfere with making an accurate measurement of the desired indent.

Experimental Results.—More or less complete data have been taken for sixteen different samples having almost the widest possible variations of hardness. In addition to the impact experiments, observations with the same samples have been made with Shore's Scleroscope and also by using Brinell's method under different maximum loads. Whilst it is quite unnecessary to give a detailed description of the results for each sample, it is highly

desirable to place on record all the observations that have been made, as well as including them in diagrammatic illustrations. Therefore, the diameters of the indents formed under different impact energies are included in Tables 4 to 19 (pages 348–355), and the whole of this information is plotted in Fig. 4. The Scleroscope hardness figures are recorded in Table 35 (page 358), and the corresponding Brinell data are given in Tables 20 to 34 (pages 356–358).

TABLE 4.—*Impact Hardness Data for Tin.*

This metal was cast in a rectangular mould and then subjected to a pressure of 50 tons. The thickness of the specimens was reduced from 1 inch to ½ inch.

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	6·29	20	5·40	4	3·76
19	6·19	15	4·92	3	3·47
18	6·14	13	4·80	2	3·33
17	6·08	11	4·70	1	2·88
16	5·95	8	4·34	—	—
13	5·74	6	4·00	—	—

TABLE 5.—*Rolled Aluminium.*

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	5·90	20	5·02	10	4·24
19	5·80	19	4·98	9	4·20
18	5·76	18	4·92	8	4·00
17	5·70	17	4·82	7	3·84
16	5·60	16	4·74	6	3·76
15	5·50	15	4·70	5	3·50
14	5·40	14	4·64	4	3·30
13	5·30	13	4·50	3	3·14
12	5·20	12	4·36	2	2·84
11	5·12	11	4·34	1	2·40

(*Continued on page* 353.)

FIG. 4.—*Diameters of the Indents formed under different Impact-Energies.*

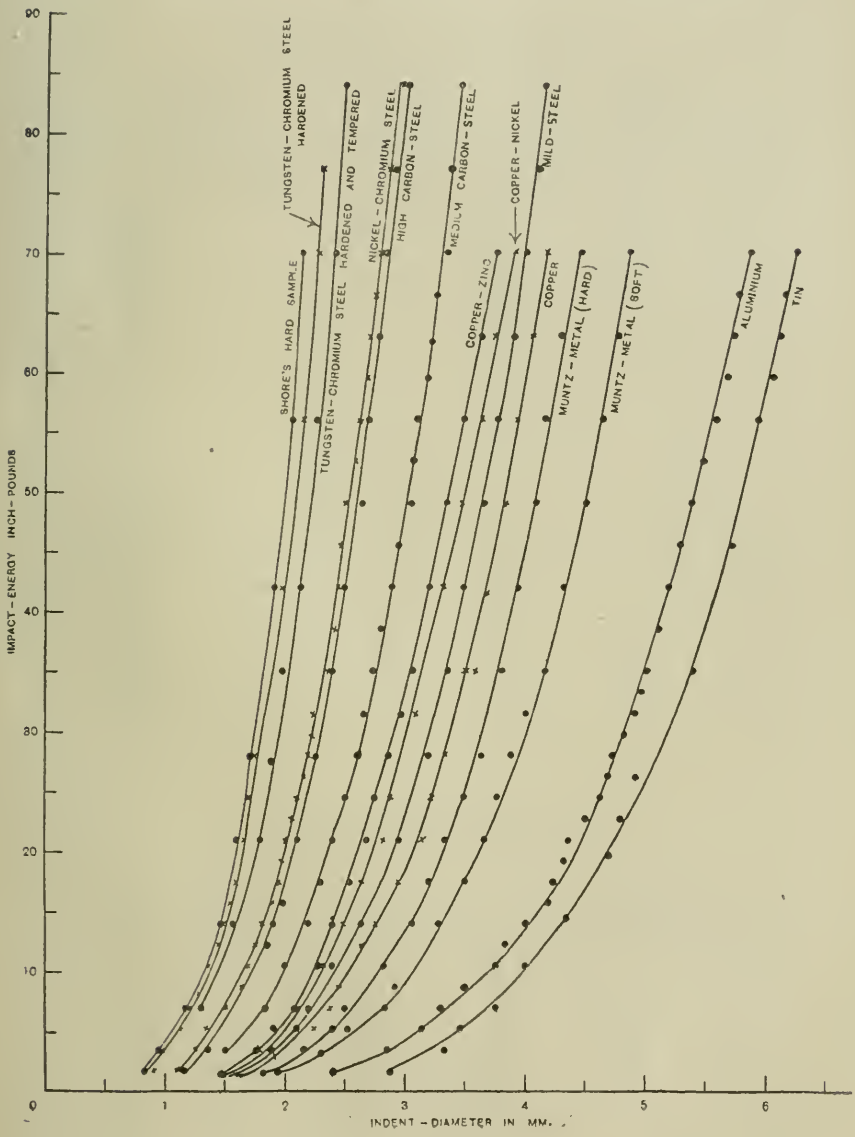


TABLE 6.—*Muntz-Metal* (*Soft*).

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	4·90	20	4·07	8	3·28
18	4·80	18	4·00	6	3·10
16	4·67	16	3·89	5	2·92
14	4·52	14	3·77	4	2·84
12	4·32	12	3·67	3	2·52
10	4·18	10	3·50	2	2·30
—	—	—	—	1	1·92

TABLE 7.—*Muntz-Metal* (*Hard*).

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	4·50	20	3·80	8	3·06
18	4·31	18	3·74	6	2·84
16	4·19	16	3·65	4	2·50
14	4·11	14	3·50	3	2·40
12	3·95	12	3·34	2	2·15
10	3·82	10	3·20	1	1·80

TABLE 8.—*Rolled Copper.*

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	4·20	20	3·50	7	2·64
18	4·07	18	3·43	6	2·58
16	3·95	16	3·33	5	2·46
14	3·86	14	3·22	4	2·38
12	3·70	12	3·16	3	2·24
10	3·60	10	2·95	2	1·88
—	—	8	2.76	1	1·60

TABLE 9.—*Mild-Steel.*

Carbon . . . . . 0·13 per cent.
Manganese . . . . . 0·40 „ „

7-lb. Weight.		3½-lb.-Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	4·84	20	4·00
19	4·78	18	3·98
18	4·72	16	3·84
17	4·62	14	3·70
16	4·50	12	3·50
15	4·44	10	3·40
14	4·36	8	3·20
13	4·30	6	2·86
12	4·20	4	2·60
11	4·14	2	2·20
10	4·04		
9	3·94		
8	3·78	1¾-lb. Weight.	
7	3·68		
6	3·50	6	2·36
5	3·36	3	2·10
4	3·20	2	1·88
3	2·94	—	—
2	2·64	—	—

TABLE 10.—*Copper-Nickel.*

20 Per Cent. Ni.

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	3·94	20	—	6	2·31
18	3·75	18	3·10	4	2·06
16	3·66	14	2·89	3	1·94
14	3·48	12	2·83	2	1·71
12	3·32	10	2·69	1	1·46
10	3·16	8	2·49	—	—

TABLE 11.—*Copper-Zinc.*

28 Per Cent. ZN.

3½-lb. Weight.		1¾-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	3·79	20	3·00	8	2·40
18	3·65	18	2·98	6	2·28
16	3·51	16	2·87	4	2 09
14	3·36	14	2·75	3	1·90
12	3·21	12	2·69	2	1·77
10	3·07	10	2·54	1	1·46

TABLE 12.—*Shore's Soft Steel.*

3½-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	3·36	20	2·80
16	3·22	16	2·65
12	3·00	12	2·46
8	2·70	8	2·22
4	2·30	4	1·83
—	—	2	1·42

TABLE 13.—*Medium Carbon-Steel.*

Carbon . . . . . 0·42 per cent.
Manganese . . . . . 0·82 „ „

7-lb. Weight.		3½-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
20	4·20	20	3·38	20	2·74
19	4·04	19	3·28	18	2·66
18	3·96	18	3·24	16	2·62
17	3·92	17	3·20	14	2·50
16	3·80	16	3·10	12	2·40
15	3·70	15	3·08	10	2·30
14	3·66	14	3·06	8	2·20
13	3·62	13	2·94	6	2·00
12	3·50	12	2·90	4	1·84
11	3·40	11	2·80	2	1·50

TABLE 14.—*High Carbon-Steel.*

Carbon . . . . . 1·00 per cent.
Manganese . . . . . 0·61 „ „

7-lb. Weight.		$3\frac{1}{2}$-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	3·60	14	2·70 and 2·66
19	3·50 and 3·50	12	2.50
18	3·42	10	2·40
17	3·38	8	2·26
16	3.30	6	2·10
14	3·20		
13	3·16	$1\frac{3}{4}$-lb. Weight.	
12	3·05		
11	2·92	9	2·00
10	2·86	8	1·90
9	2·80	7	1·84
8	2·72	4	1·64
—	—	2	1·36
—	—	1	1·14

When about half the number of samples experimented with had been examined under the impact test and the results had been plotted, the similarity between the character of the different curves was so evident that it was decided to work out the equations for each case. At first this was roughly done, but the expressions thus found had a very remarkable resemblance to one another. They could be generalized as follows:—

$$d = CE^n,$$

Where d = diameter of impression in mm^2, C = a constant which differed considerably for each metal, E = the energy of impact and n = a constant which only varied between the limits of about 0·24 to 0·27. At this stage the Authors were of the opinion that the equations might better fit the experimental curves if the value for n were kept the same for each case, but they did not, at the time, endeavour to inquire into this, because it was considered more important to extend the experimental observations to a wider range of metals. With this in view, samples were selected for

(*Continued on page* 358.)

TABLE 15.—*Nickel-Chromium Steel, Air-Hardened.*

Nickel	3·66 per cent.
Chromium	0·86 ,, ,,
Carbon	0·33 ,, ,,
Manganese	0·48 ,, ,,

7-lb. Weight.		$1\frac{3}{4}$-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	3·44	20	2·36
19	3·38	19	2·28
18	3·34	18	2·24
17	3·26	17	2·22
16	3·24	16	2·20
15	3·20	15	2·16
14	3·12	14	2·10
13	3·10	13	2·04
12	3·00	12	2·00
11	2·90	11	1·98
		10	1·96
		9	1·90
$3\frac{1}{2}$-lb. Weight.		8	1·80
20	2·82	7	1·76
19	2·78	6	1·70
18	2·72	5	1·64
17	2·70	4	1·50
16	2·64	3	1·34
15	2·60	2	1·26
14	2·50	1	1·10
13	2·48	—	—
12	2·46	—	—
11	2·42	—	—

TABLE 16.—*Chromium-Carbon Steel, Hardened.*

Chromium	6·18 per cent.
Carbon	0·37 ,, ,,

7-lb. Weight.	
Height.	Indent in mm.
inches.	
15	2·84
13	2·74
11	2·54
9	2·44

TABLE 17.—*Tungsten-Chromium Steel* (*Hardened and Tempered*).

Tungsten. Chromium. Carbon
8·0 6·0 0·60 per cent.

7-lb. Weight.		3½-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.		inches.	
16	2·67	20	2·42	20	1·97
12	2·54	16	2·28	16	1·90
10	2·44	12	2·15	12	1·80
—	—	8	1·90	8	1·56
—	—	—	—	4	1·30

TABLE 18.—*Tungsten-Chromium Steel* (*Hardened*).

Same composition as above.

7-lb. Weight.		1¾-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	2·62	16	1·74
17	2·54	14	1·70
14	2·46	12	1·66
11	2·34	10	1·60
		9	1·54
		8	1·48
		7	1·44
3½-lb. Weight.		6	1·36
		5	1·28
20	2·30	4	1·20
16	2·16	3	1·12
12	1·98	2	0·98
—	—	1	0·94

TABLE 19.—*Shore's Hard Sample.*

7-lb. Weight.		3½-lb. Weight.	
Height.	Indent in mm.	Height.	Indent in mm.
inches.		inches.	
20	2·55	20	2·16
		16	2·08
1¾-lb. Weight.		12	1·92
16	1·70	8	1·71
12	1·60	4	1·46
8	1·42	—	—
4	1·17	—	—
2	0·95	—	—
1	0·84	—	—

TABLE 20.—*Tin* (*Pressed*).

Load.	Indent.	Hardness No.
Kg. 500	6·00	16

TABLE 21.
Aluminium (*Rolled*).

Load.	Indent.	Hardness No.
Kg. 500	3·84	41
1,000	5·40	40
1,500	6·66	38
—	—	—
—	—	—

TABLE 22.
Muntz-Metal (*Soft*).

Load.	Indent.	Hardness No.
Kg. 500	3·16	62
1,000	4·28	66
1,500	5·07	75
2,000	5·78	69
2,500	6·10	77

TABLE 23.
Muntz-Metal (*Soft*).

Load.	Indent.	Hardness No.
Kg. 500	2·74	83
1,000	3·72	88
1,500	4·44	92
2,000	5·00	95
2,500	5·65	91
3,000	6·00	95·5

TABLE 24.
Copper.

Load.	Indent.	Hardness No.
Kg. 500	2·22	122·5
1,000	3·12	127
1,500	3·84	124
2,000	4·36	127
2,500	4·84	127
3,000	5·36	123

TABLE 25.
Mild-Steel.

Load.	Indent.	Hardness No.
Kg. 500	2·34	115
1,000	3·34	111
1,500	4·00	114
2,000	4·60	114
2,500	5·06	116
3,000	5·50	116
3,500	5·82	119

TABLE 26.
Copper-Nickel Alloy.

Load.	Indent.	Hardness No.
Kg. 500	2·00	158
1,000	2·82	157
1,500	3.48	153
2,000	3·96	156
2,500	4·37	159
3,000	4·85	152
3,500	5·28	148

TABLE 27.

Copper-Zinc Alloy.

Load.	Indent.	Hardness No.
Kg.		
500	1·94	168·5
1,000	2·72	167
1,500	3·29	171
2,000	3·76	173·5
2.500	4·12	179
3,000	4·52	177

TABLE 28.

Shore's Soft-Steel.

Load.	Indent.	Hardness No.
Kg.		
2,000	3·56	194
2,500	3·74	219
3,000	4·04	224
3,500	4·42	216
—	—	—
—	—	—

TABLE 29.

Medium Carbon-Steel.

Load.	Indent.	Hardness No.
Kg.		
500	1·92	171
1,000	2·66	177
1,500	3·00	207
2,000	3·50	211
2,500	3·70	224
3,000	4·00	228
—	—	—

TABLE 30.

High Carbon-Steel.

Load.	Indent.	Hardness No.
Kg.		
500	1·60	248
1,000	2·24	249
1,500	2·68	261
2,000	3·00	277
2,500	3·28	287
3,000	3·50	302
3,500	3·72	310

TABLE 31.

Nickel-Chromium Steel, Air-Hardened.

Load.	Indent.	Hardness.
Kg.		
1,000	2·10	287
1,500	2·42	323
2,000	2·76	327
2,500	3·01	336
3,000	3·32	336
3,500	3·60	333

TABLE 32.

Tungsten-Chromium Steel, Hardened and Tempered.

Load.	Indent.	Hardness.
Kg.		
2,500	2·46	520
3,000	2·64	535
3,500	2·80	555
4,000	3·00	551
	Chromium-Steel.	
3,000	2·80	477

TABLE 33.

Tungsten-Chromium, Hardened.

Load.	Indent.	Hardness.
Kg.		
2,000	2·00	630
2,500	2·26	617
3,000	2·40	652
3,500	2·50	700
—	—	—

TABLE 34.

Shore's Hard Sample.

Load.	Indent.	Hardness.
Kg.		
2,500	2·18	655
3,000	2·32	700
3,500	2·42	744
4,000	2·64	712
4,500	2·76	735

TABLE 35.

Sample.	Energy of Impact to give 2·5 mm. Indent with 10 mm. Ball.	Brinell Hardness Nos.	Scleroscope Hardness.
Tin	0·75	16	6
Aluminium	1·75	41	8
Muntz-Metal, Soft	5·25	77	12
Muntz-Metal, Hard	7·0	95	17
Copper	9·6	127	23·7
Mild-Steel	12·25	116	18
Copper-Nickel, 20 per cent. Ni	14·0	159	28·5
Copper-Zinc, 28 per cent. Zn	16·6	179	33·5
Shore's Soft Steel	22·75	224	34
Medium Carbon Steel	24·5	228	25
High Carbon Steel	39·0	302	41
Nickel-Chromium, Air-Hardened	45·0	336	46
Chromium-Carbon, Steel-Hardened	70·0	477	60
Tungsten-Chromium, Hardened and Tempered	78·75	535	61
Tungsten-Chromium Steel, Hardened	110·0	652	70
Shore's Hard Steel	138·0	700	95

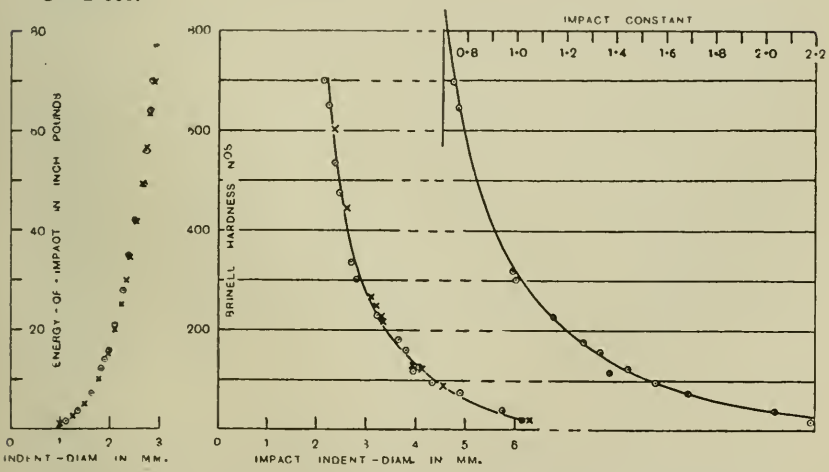
further investigation so as to get as great a variety of hardness as possible. When this had been done, each curve was again examined with greater care, and it was found that they agreed, much closer than could possibly have been anticipated, with the above general equation when the value for n was 0·25 in all cases. All the

curves have been carefully checked, over their entire length, with the above equation when using their respective values for the constant C, and it was found that the theoretical curves thus obtained corresponded almost exactly with the experimental observations. A typical example is shown in Fig. 5, where the dots are observed points and the crosses are the diameters of indents calculated from the equation $d = CE^{\cdot 25}$. In the Authors' opinion this is a noteworthy discovery, because it means that the value of the

FIG. 5.
High-Carbon Steel.
Dots show diameters experimentally determined. Crosses show diameters calculated from equation
$d = C \times E^{\cdot 25}$
$C = 1 \cdot 000$.

FIG. 6.
Brinell Hardness Nos. and Impact Diameters with 63 inch-lb. Impact.

FIG. 7.
Brinell Nos. and Impact Constants.



constant C is a true measure of the hardness of the metal expressed in terms of its resistance to penetration, when tested under an impact blow. As will be shown later, these constants appear to be a more accurate indication of the same kind of hardness as the Brinell method aims at estimating. The chief difference between the two methods is that the time-factor, which is an objectionable feature leading to an uneven hardness scale in the Brinell method, is entirely eliminated in the impact method.

It may be advisable to state that the values for the constants C can only be expected to apply when the specimens are rigidly held in such a way as to enable them to take up all the energy they are capable of absorbing from, and at the instant of, the impact. If these conditions are fulfilled, the deformation will be confined to the zone immediately under, or concentrated within a very limited area around, the ball. The impact method cannot be expected to differentiate between two particular kinds of hardness, such as that of an ordinary carbon-steel and the characteristic hardness of manganese-steel, any more than the ordinary Brinell method.

With the above equation, and knowing the value of C for any given metal, it is possible to calculate the energy of impact that would be required to produce any stated diameter of indent when using a 10 mm. ball. This should be true, for the softer metals, for diameters up to that of the ball, but with hard materials such a high degree of plastic deformation would not be possible without causing fracture of the specimen or the ball.

It would be very interesting to determine how the values for C, and n are influenced by changes in the diameter of the ball. Since C is apparently a true measure of the hardness of a metal, it may be useful to point out that its value can be determined from one careful measurement of an indent produced by a known impact, for it equals the diameter in mm. divided by the $\sqrt[4]{\ }$ of the energy of impact which made the indent or

$$C = \sqrt[4]{\frac{d}{E}},$$

The value of C for the various materials which have been examined are tabulated in Table 36 (page 361).

In practice it would be advisable to make more than one observation, but comparatively small indentations only need be made, if sufficient care is taken in making the measurement of the indent. Both for small indents made by impact and by Brinell's method, the Authors have found it necessary to measure the diameters at higher magnifications than are usually adopted. For this purpose they have found that the most reliable results are

obtained when the indent is examined through a microscope by throwing the image, at a magnification of 24 diameters, on a graduated ground-glass screen. In this way the personal element, which is rather a serious factor when measuring small impressions by means of any of the instruments that are supplied by makers of the Brinell apparatus, is entirely removed.

It does not appear to be satisfactory to use the figures representing the constants C, as they stand, to express the hardness of metals, both because they are inconveniently small, and

TABLE 36.

Values of Constants (C) for the Different Materials Tested.

Material.	Constant (C).
Tin	2·186
Aluminium	2·040
Muntz-Metal, Soft	1·694
Muntz-Metal, Hard	1·556
Copper	1·450
Mild-Steel	1·375
Copper-Nickel, 20 per cent. Ni	1·336
Copper-Zinc, 28 per cent. Zn	1·27
Shore's Soft Steel	1·162
Medium Carbon-Steel	1·150
High Carbon-Steel	1·000
Nickel-Chromium Steel, Air-Hardened	0·986
Chromium-Carbon Steel, Hardened	0·850
Tungsten-Chromium Steel, Hardened and Tempered	0·839
Tungsten-Chromium Steel, Hardened	0·768
Shore's Hard Steel	0·748

also because their magnitudes vary in the inverse direction of the hardness. Much better use can be made of them by calculating the impact energy that would be required to make an indent of exactly the same dimensions for all samples that are examined. The hardness could then be represented as the amount of impact energy, in inch-lb., necessary to produce a certain standard indentation. On this basis the Authors have calculated the energy required to give an indent of 2·5 mm. for all the samples they have examined; the results are shown in Table 35 (page 358). A diameter of 2·5 mm. has been chosen because it is one which it

may be possible to approach, if not actually reach, when testing the hardest steel, and it is not too small for the softest metal.

In this way the Authors believe that the advantages of the dynamic method of testing the hardness of metals, over that of the static load, may be very briefly stated as follows:—

(1) The time-factor is entirely eliminated.

(2) By means of the equation $d = CE^{\cdot 25}$, whereby the energy required to produce a standard-sized indent can be calculated, the influence of cold work can be corrected for, and the hardness values thus obtained are strictly comparable.

(3) The impact method gives a new hardness scale in energy units, and each unit on any portion of this scale has the same significance as those on any other section.

Although it should be possible to make an impact instrument, such as the Authors have used, at a much lower cost than those which are now made for testing under static loads, and in spite of the fact that the hardness scale of the former method appears to offer many real advantages over the latter, even if it is considered advisable to adopt the impact scale of inch-lb. as the standard, it does not at present seem necessary to suggest that the static method should be abandoned. Judging from a careful comparison of the experiments with the dynamic and static tests which the Authors have made, it is an easy matter accurately to convert the hardness values of one scale into those of the other.

To illustrate that this can be done, reference will be made to Fig. 6, where the dots represent the diameters of indents made, when using the second impact machine, with an impact energy of 63 inch-lb., plotted against the Brinell hardness-numbers. The equation for this curve is

$$H = \frac{7455}{d^3},$$

where H is the Brinell-number and d is the diameter of impact indent. For the purpose of comparison the indent diameters that

were obtained with the first impact instrument have been placed on the same diagram. They are represented by X, and it will be seen that the results from the two instruments, which were absolutely different, are in very good agreement with each other. Thus with an accurately measured indent produced under known impact energy, the value of the impact constant C can be estimated as follows:—

$$C = \sqrt[4]{\frac{d}{E}},$$

from which the diameter with an impact of 63 inch-lb. can be calculated as

$$C \sqrt[4]{63} = d.$$

In a more direct way the constant C can be estimated from Fig. 7, where the impact constants C are plotted against Brinell numbers. The only observation which does not fall on this curve is the one for mild steel.

A Comparison of the Brinell, Scleroscope, and impact Indent, Hardness Scales.

A comparison of these three hardness scales is obtained almost at a glance in Fig. 8. In this diagram the energy of impact required to make an indent of 2·5 mm. in all the materials tested have been plotted as an absolute scale. In conformity with this scale have been plotted the maximum Brinell hardness-numbers that were obtained with a load not exceeding 3,000 kg., and the direct readings of the Scleroscope.

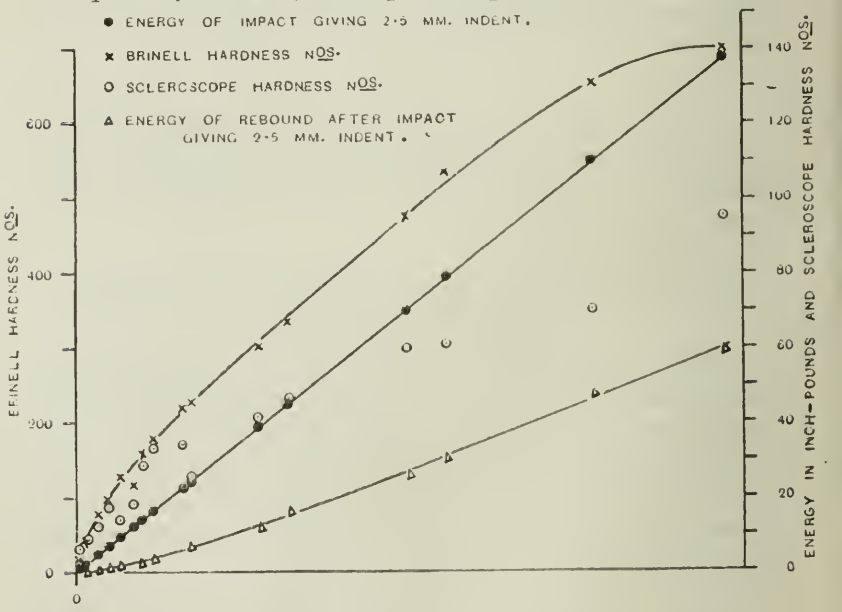
The more or less general convexity of the curve representing the Brinell hardness-numbers demonstrates very clearly what has been previously stated, namely, that as the hardness of the metal increases there is a tendency for the Brinell method to give hardness-numbers which are lower than should be indicated if the true hardness of the materials were obtained. This defect is not very marked for hardnesses up to about 200, for as will be seen the points up to that zone approximate to a straight line; with higher hardnesses, however, the points fall away very considerably from

this supposed straight line, and for something above, say, 550, there is a pronounced curvature to the right.

If a greatly extended series of tests were made, more particularly with very hard materials, and these were to confirm the direction of the Brinell curve in Fig. 8, as the Authors believe they would, then one cause of the difficulty in obtaining satisfactory indications of the hardness of very hard metals would be revealed. Apparently this

Fig. 8.

Comparison of the Brinell, Scleroscope, and Impact Indent, Hardness Scales.



difficulty is one which is governed by the fact that the Brinell scale of $\frac{\text{Load}}{\text{Area}}$ does not give a true indication of the intrinsic hardness of metals when the load is gradually applied.

As regards the Scleroscope numbers, which are plotted in Fig. 8, it will be seen that they are far too irregular to allow of anything being said in their favour. Two facts can be advanced to account for the unsatisfactory results of the Scleroscope. These are (1) the

amount of deformation produced differs with materials of varying hardness, and no correction is made for this; and (2) unlike the impact method used by the Authors, the degree of deformation produced is relatively so small that the height of rebound is very materially influenced by the nature of the surface and by the internal structure of the metal. The effect of structure in this connexion is revealed with the two samples designated Shore's soft steel, and medium carbon steel; the former is shown to be a little

TABLE 37.

Rebound Experiments using new Impact Instrument, $1\frac{3}{4}$-lb. weight falling 20 inches.

Material.	Height of Rebound.
	inches.
Tin	1
Aluminium	1·25
Muntz-Metal, Soft	1·75
Muntz-Metal, Hard	2·5
Copper	4·5
Mild-Steel	3·12
Copper-Nickel, 20 per cent. Nickel	4·87
Brass, 28 per cent. Zinc	4·80
Shore's Soft Steel	4·50
Medium Carbon Steel	5·50
Hard Steel, High Carbon	6·25
Nickel-Chromium, Air-Hardened	7·00
Chromium-Carbon Steel	7·50
Tungsten-Chromium, Hardened and Tempered	7·75
Tungsten-Chromium, Hardened	8·50
Shore's Hard Steel	7·75

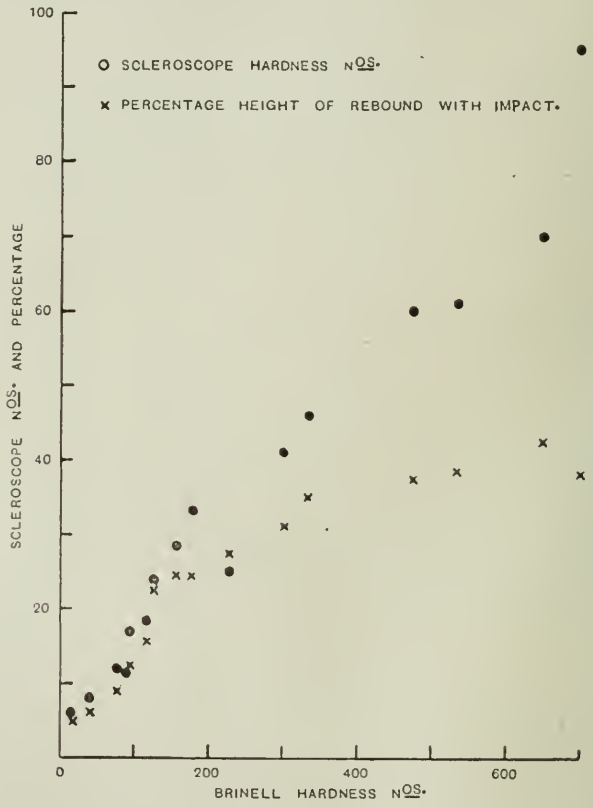
softer than the latter both by the Brinell and impact methods, whilst the Scleroscope indicates quite a marked difference in the reverse direction.

Whilst the Authors have not made a systematic examination of the height to which the hammer rebounded from the metals tested with the new impact instrument, a few careful observations have been made, and a brief reference will now be made to the results. All the measurements were made with the hammer weighing $1\frac{3}{4}$ lb. after falling 20 inches. Some difficulty was at first experienced in

getting satisfactory readings, but after a little practice and a number of trials for each sample, results were got which the Authors believe are very nearly accurate. These are recorded in Table 37 (page 365) and plotted alongside the Scleroscope numbers

Fig. 9.

Comparison of Scleroscope Hardness Nos. with Heights of Rebound using new Impact Instrument. Fig. 3 (page 345).



in Fig. 9. In their present form these are not very instructive, but as a matter of interest they have been used in conjunction with the indent measurements, etc., for calculating the energy of rebound they represent, if the energy of impact were sufficient to

give an indent of exactly 2·5 mm. The data calculated in this way have been plotted in Fig. 8, from which it will be seen that quite a smooth curve is obtained.

With the limited amount of information relating to the question of rebound, which the Authors have at their disposal, they do not wish to make any definite conclusions, but prefer to wait until an extensive series of experiments in this direction, which it is proposed to make, are completed. Nevertheless, the irregularity of the data as plotted in Fig. 9, coupled with the fact that they fall upon a smooth curve as in Fig. 8, when they have been reduced to standard conditions, very strongly supports the view which the Authors have previously put forward; namely, that results obtained from rebound experiments cannot be regarded as satisfactory unless the height from which the hammer falls is so regulated that the degree of penetration is the same for all tests, or, unless the necessary corrections are made to enable the observations to be expressed in terms which correspond to standard conditions. Failing this, it would appear that the rebound scale is very irregular and untrustworthy.

Summary.—The conclusions which the Authors draw from the foregoing investigation may be summarized as follows:—

(1) When using a 10 mm. hardened steel ball rigidly fixed into a hammer, reliable hardness tests can be readily made, and the dimensions of the indent produced with known impact energy may be converted into terms of Brinell hardness-numbers.

(2) The results obtained indicate that there is a law governing the resistance to penetration of metals which are capable of plastic deformation. This law, which applies to the very soft metals and to hardened tool steel, may be expressed by the equation:—

$$d = CE^{\cdot 25},$$

where d equals the diameter of the indent made by a 10 mm. ball, C equals a constant which varies with the

hardness of the metal, and E equals the total energy of impact.

(3) Whilst the factor C is a true measure of the intrinsic hardness of metals, it would scarcely be convenient to use it, as it stands, for expressing the hardness. A much better way is to use the factor for any particular metal, and the above equation for calculating the energy of impact required to give an indent of standard dimensions. In this way a new hardness scale is obtained in inch-pounds impact energy, which is regular throughout its length.

(4) By using the impact method, or scale, the two factors—time and degree of deformation—which have different effects with materials of varying hardness, are entirely eliminated. When the hardness is estimated by a gradually applied load, these two factors cause a serious distortion of the hardness scale.

(5) On account of the influence of time and the varying degree of deformation produced with loads which are gradually increased to a maximum, the Brinell scale is not really satisfactory. In cases where time and extent of deformation do not cause serious errors in this connexion, such as with very hard specimens, the third difficulty of deciding upon the maximum load which should be applied comes into prominence.

(6) The method of estimating the hardness by the rebound of a hammer after falling from a fixed height is unreliable. It would appear that this method can only be expected to give a regular scale if the energy of impact is so adjusted that the same amount of penetration is obtained in all tests. If this is not done, the indent should be measured and the observed rebound corrected to that which would occur if a standard indent were produced. Further, the impact should be sufficiently large to give quite a substantial indentation in order to minimize the influence of the character of the surface and the internal structure of the metal.

In conclusion, the Authors wish cordially to express their thanks to Sir Henry Fowler, K.B.E., the Superintendent of the Royal Aircraft Factory, for the assistance he has given and for the keen interest he has taken in the progress of the work.

The Paper is illustrated by 9 Figs. in the letterpress.

References.

(1) Axel Wahlberg, "Brinell Method of determining Hardness." Journal, Iron and Steel Institute, 1901, Vol. I, pages 243–298; Vol. II, pages 234–271.

(2) J. A. Brinell & Gunnar Dillner, "The Brinell Hardness-test and Its Practical Application." International Congress for Testing Materials, Brussels Congress, 1906.

(3) W. N. Thomas, "A few Experiments on the Hardness Testing of Mild Steel." Journal, Iron and Steel Institute, 1916, Vol. I, page 255.

MEMOIRS.

William Sloane Accles was born at Bendigo, Australia, on 1st October 1856. He served his apprenticeship at Colt's Armoury in Hartford, Conn., and was subsequently with the firm of Pratt and Whitney, of the same town. For several years he was manager of his brother's works at Birmingham, namely, Messrs. Grenfell and Accles, afterwards Accles, Ltd., who introduced the Gatling Gun, and later the Accles machine gun. In about 1895 he joined the Niles Tool Co., and in the following year became its manager in Europe with headquarters in London. In 1900 the Niles Co. purchased the Pratt and Whitney Co., whose works became famous for their special rifle-making machinery; and subsequent amalgamations caused the title of the firm to be changed to the Niles-Bement-Pond-Co., of which he remained European Manager until his death. During his long connexion with the firm he travelled extensively on their behalf, and was successful in obtaining orders of great magnitude. His death took place at his residence in Kensington, on 26th January 1918, at the age of sixty-one. He became a Member of this Institution in 1894.

Captain **ERIC EARLE BARNES, R.E.**, was born in London on 17th August 1891. His early education was acquired at a private school in Ealing and at St. Paul's School, Kensington. In January 1909 he began an apprenticeship at the locomotive works of the London and North Western Railway, Crewe, and on its completion in 1912 he returned to London. In 1914 he joined the Forces, receiving a Commission in the Royal Engineers, and in 1916 he was promoted to Captain. His death took place in action in France on 7th November 1917, at the age of twenty-six. He became a Graduate of this Institution in 1910.

Joseph Barrow was born at Disley, near Stockport, on 16th October 1831. At the age of fourteen he was apprenticed to Messrs. Jones and Potts, locomotive engineers, of Newton-le-Willows, and later was employed at Whitworth's Works for about five years. He then went to Messrs. Beyer, Peacock and Co., Gorton, for a time, and subsequently was engaged at the works of Sir Peter Fairbairn, Leeds. In 1884 he entered into partnership with Messrs. Thomas Shanks and Co., of Johnstone, and during his long connexion with that firm he gave much attention to the design of machines for producing large screws. Among other inventions of his may be mentioned turbine boring machines, the V. and H. planes for accurate surfacing, and lathes for turning the largest diameter l.p. rotors. In 1908 he retired from the firm, and went to live at Northwood, Middlesex, where his death took place on 13th January 1918, at the age of eighty-six. He became a Member of this Institution in 1862, and for very many years was one of the most constant attendants at the Summer Meetings.

Sir John Wolfe Barry, K.C.B., LL.D., F.R.S., was born in London, on 7th December 1836, being the fifth and youngest son of Sir Charles Barry, R.A., who was the architect of the Houses of Parliament. The early part of his education was acquired at Trinity College, Glenalmond, after which he came to King's College, London. On completing his course there he served for some time in the employment of Messrs. Lucas Brothers, engineering contractors, and then became articled to Mr. (afterwards Sir) John Hawkshaw, by whom he was employed as assistant resident engineer in connexion with the building of Charing Cross railway bridge and station, and as resident engineer in charge of the construction of the Cannon Street railway bridge, and the station at its northern end. In 1867 he started to practise on his own account as a consulting engineer, and from then onwards he was connected with some of the most important engineering works carried out in this country. From 1878 the late Mr. H. M. Brunel was a partner with him until his death in 1903, Mr. A. J. Barry

from 1892 till 1900, the late Mr. C. A. Brereton from 1892 until 1909, Mr. G. E. W. Cruttwell and Mr. K. A. Wolfe Barry since 1901, and Mr. A. G. Lyster from 1913. Sir John's work was more closely identified with facilities for transport than with any other branch of engineering. He designed and carried out extensions and improvements of the Metropolitan District and Metropolitan Railways and (in conjunction with Sir John Hawkshaw) the works of the "Inner Circle" completion between Mansion House and Aldgate with the extension to Whitechapel; branch railways for the London and Brighton and the London Chatham and Dover Railways in the South of England, and for the Caledonian Railway in Scotland. The St. Paul's bridge and station at Blackfriars for the London Chatham and Dover Railway were also designed and carried out by him. He was called in to advise, in conjunction with Sir Horace Jones, the City Corporation on the question of a road bridge over the Thames east of London Bridge, and the bascule system for the opening span was decided upon. Sir Horace Jones died soon after the commencement of the work, so that the carrying out of the undertaking rested almost exclusively with Sir John. The King Edward the Seventh Bridge at Kew was also built by him and his partners.

In dock construction the work carried out by Sir John was most extensive, including many of the largest docks in the country. He was the engineer responsible for the construction of the Barry Docks and the important new dock at Grangemouth; also for improvements and extensions of Tyne Dock, Surrey Commercial Docks, Middlesbrough Dock, and Limehouse Dock. Together with the partners in his firm he was engineer for the new docks at Immingham and Newport (Mon.), and in conjunction with his partner the late Mr. C. A. Brereton and Sir Benjamin Baker and Mr. C. A. Hurtzig (both of whom also predeceased him) he was consulting engineer for the construction of the new docks at Avonmouth and for the new Joint Dock at Hull.

He was one of the consulting engineers for the Bombay Port Trust, and has held appointments as consulting engineer to the Government of Natal and to the Caledonian, North Eastern,

London Chatham and Dover, Metropolitan, Metropolitan District, and Bengal-Nagpur Railways, and for various railways in China. He has been connected with important works carried out in India, China, and South Africa, and from 1892 to 1906 was one of the British Representatives on the International Commission on Works of the Suez Canal. He was a member of the Court of Arbitration together with Sir Edward Fry and Sir Hugh Owen in connexion with the purchase of the water companies' undertakings for absorption by the Metropolitan Water Board, and served on many important Royal Commissions.

Sir John occupied the Presidential Chair of the Institution of Civil Engineers in 1896–7, of which he was elected an Honorary Member in 1916. He was elected a Member of this Institution in 1871, and a Member of Council in 1901; in 1913 he became a Vice-President, a position which he resigned in 1915, although still retaining a seat on the Council. He was a Fellow of the Royal Society from 1895, a Member of the Royal Institution, and Chairman of Council of the Royal Society of Arts in 1898–9. In 1897 he became Knight Commander of the Bath, his Companionship having been granted in 1894, when the Tower Bridge was opened. He took a very great interest in the advancement of technical education, and it was largely through his influence that the City Guilds became more intimately identified with this work; for a long period he was Chairman of the Executive Committee of the City and Guilds Institute, and was on the Executive Committee of the National Physical Laboratory from the time of its foundation. He took a leading part in the formation of the Engineering Standards Committee in 1901, and was chairman almost from its commencement. He was a strong advocate of Lord Roberts' movement for National Service, and was one of the earliest members of the Queen's Westminster Volunteers. He was Colonel in the Engineer and Railway Staff Corps. As Chairman for many years of the Eastern Telegraph and its associated companies, he occupied an important position in the business world. His death took place at his residence at Chelsea Embankment, London, on 22nd January 1918, at the age of eighty-one.

William Boyd was born in London on 26th April 1869. He began his engineering career as an apprentice in the locomotive shops of the London and South Western Railway at Nine Elms, and eighteen months later became a pupil with Messrs. Woodhouse and Rawson for two years. In 1891 he was appointed superintending engineer to the Epstein Electric Accumulator Co., and held this position until 1898 when he became an assistant engineer on the staff of the Central London Railway at Shepherd's Bush. In 1902 he was appointed manager, engineer, and secretary of the Northwich Electric Supply Co., retaining these positions until his death; and during that period the business of the Company was greatly developed. His death took place in Manchester on 12th January 1918, in his forty-ninth year. He was elected an Associate Member of this Institution in 1900.

James Buchanan was born in Liverpool on 20th November 1853. He was educated at schools in Liverpool, after which he served his apprenticeship from 1868 to 1873 in the works of his father, in Liverpool. On its completion he became Works Manager, and was taken into partnership in 1877, when the name of the firm was changed to that of James Buchanan and Son; he became sole partner in 1892 of the Caledonia Foundry and Engine Works, Brasenose Road, Liverpool. Under his direction the business made considerable progress, mainly in connexion with the sugar refining industry, brickworks, by-product coke-oven machinery, &c., and he was the inventor of several machines and appliances connected with those industries. At the outbreak of war he undertook important Government contracts, installing an extensive plant for the production of munitions. Mr. Buchanan was a Past-President of the Liverpool Polytechnic Society, President of the Liverpool Engineering Employers' Association, and was a Member of the Council of the Engineering Employers' Federation. His death took place in Liverpool on 21st November 1917, at the age of sixty-four. He became a Member of this Institution in 1899.

Angus Campbell was born in Liverpool on 10th May 1831.

His early life was spent in Scotland, after which he worked in Woolwich Arsenal, where he held the position of master founder during the Crimean War, and superintended the manufacture of shells and other munitions. In 1857 he went to India under covenant with the East India Company as assistant superintendent of the Kumaon Iron Works. On the closing of the works owing to the difficulty of obtaining fuel, he entered the Public Works Department as assistant superintendent of the Canal Foundry and Workshops at Roorkee, and became Superintendent in 1864. From that time until his retirement, under the age rule, in 1886, he was entrusted with the designing and carrying out of many important and successful engineering projects in Northern India. In those days private enterprise scarcely existed in India, and the workshops at Roorkee met the demand of Government and private individuals and companies for a great variety of manufactured articles. Among Mr. Campbell's inventions was a heliograph which has since then been the only one used by the Army in India. Another invention was a machine for measuring the links in survey chains. After retiring from the service of the Government he resided in Mussoorie and Dehra Dun, U.P., and was engaged on many engineering projects until within a year or two before his death. He designed and carried out schemes for supplying Dehra Dun and the hill station of Mussoorie with water, and prepared a system of sanitation for the latter place. His death took place at Mussoorie on 12th August 1917, at the age of eighty-six. He became a Member of this Institution in 1877.

FRANK EVANS CHIVERS was born near Bath on 13th February 1870. He received his early education at Fortesque College, Radstock, and served an apprenticeship of four years at Writhlington Foundry, near Radstock. In 1888 he went to London, where he was engaged as draughtsman for a year at each of the following firms, Messrs. Dewrance and Co., Messrs. J. and G. Rennie, and Messrs. Maudslay, Sons and Field. During this period he studied in the evenings at the Regent Street Polytechnic. Early in 1892 he was engaged by Messrs. G. Kent, hydraulic

engineers, of Holborn, London, and later in the year went, on their behalf, to Brazil, as assistant superintendent of the mechanical department of the Beberibe Water Works, Pernambuco. Two years later he was appointed Superintendent of the same works, and continued in this position until his death, which took place at Pernambuco on 21st December 1916, in his forty-seventh year. He was elected an Associate Member of this Institution in 1903.

Sir William Coddington, Bart., was born at Salford on 12th December 1830. At the age of twelve his parents removed to Blackburn where he received his early education. Subsequently he and his brothers were taken into partnership by their father, who owned the Ordnance, Crossfield, and Wellington Old and New Cotton Mills in Blackburn, and the title of the firm became W. D. Coddington and Sons. In 1862 the principal management of the business devolved upon him, and in course of time he became the sole proprietor, retaining in his own hands the direction of the firm's large business up to the last. In addition to the spinning and manufacturing concerns, the firm also engaged at one time in the Manchester trade as bleached cotton merchants. He built the Wellington new mill in 1872, and to-day the four mills contain over 98,000 spindles, and nearly 2,000 looms. He was thoroughly conversant with every process of the industry, from the raw cotton to the bleached cloth. He took a great interest in local affairs, and was elected on the Town Council of Blackburn in 1873, and in the following year became Mayor. In 1880 he was elected Member of Parliament for Blackburn, which seat he held for nearly twenty-six years, and in 1896 he was created a Baronet. The Town Council honoured him by conferring the Honorary Freedom of the town in 1912 at the same time as Viscount Morley of Blackburn received it. He was placed on the Commission of the Peace for the County in 1867, and subsequently was created a Deputy Lieutenant. His death took place at his residence, Wycollar, Blackburn, on 15th February 1918, at the age of eighty-seven. He became a Member of this Institution in 1864.

Engineer-Captain EDWIN CORNISH, R.N., was born in 1857. He served as an engineer student from 1872 to 1878 at the Royal Dockyards, Sheerness and Chatham, where he received his practical and theoretical education in engineering. He entered the Royal Navy as assistant engineer in 1878, and received a further course of instruction at the Royal Naval College, Greenwich, until 1879, in which year he was appointed to H.M.S. "Eclipse." From 1883 to 1885 he was engineer on H.M.S. "Slaney," and until 1889 on H.M.S. "Constance," when he became engineer-in-charge at H.M. Dockyard, Halifax. He held this post for three years, and was then appointed chief engineer to H.M.S. "Brilliant." In December 1899 he was promoted to Fleet-Engineer, and four years later to Engineer-Commander, serving on H.M.S. "Africa" and H.M.S. "Cressy." In 1908 he became Engineer-Captain, and in the following year he served in H.M.S. "Shannon," in the Second Cruiser Squadron. He was placed on the retired list in January 1912, but in 1914 on the outbreak of war he returned to the Admiralty for a time, after which he was appointed Chief of Overseers for the Tyne District and Scotland. In 1915 he was sent to Malta on special work and thence to Genoa, where his death took place on 23rd September 1917, at the age of sixty. He became a Member of this Institution in 1895.

Captain **ARTHUR NORMAN COUSIN**, York and Lancaster Regiment, was born in London on 8th May 1891. His early education was received at the High School, Dorking, after which he went to University College, London, where he graduated B.Sc., with 1st Class Honours (Engineering). Subsequently he became Student Demonstrator in Applied Mathematics at the same College. In September 1914 he was gazetted Lieutenant in the York and Lancaster Regiment, promoted Captain a year later, and proceeded to Egypt in December 1915. He subsequently saw much service in France, occupying the post of Brigade Intelligence Officer, and shortly before his death was made Adjutant in his old Battalion. He was killed in action on 7th December 1917, at the age of twenty-six. He was elected a Graduate of this Institution in 1912.

Flight - Commander **PERCY CUTHBERT DOUGLASS DOUGLASS, R.N.A.S.**, was born at St. Mary's, Scilly Isles, on 28th September 1886. He was educated at Marlborough College and under private tutors, and at the age of nineteen was articled to his father, the late Mr. W. T. Douglass,* of Westminster. He received the practical side of his engineering education from 1906 to 1908 at the works of Messrs. Andrew Barclay and Co., Kilmarnock, the Steel Co. of Scotland, and Messrs. Simons and Co., Renfrew, after which he returned to assist his father in the preparation of plans, specifications, and inspections of lighthouse lanterns, apparatus, machinery, steel towers, gas buoys and gas-making plant. In 1910 he was appointed assistant resident engineer for the Buckie Harbour Extension Works, which his father was building. Two years later he returned to work in the London office, but was only there a few months before his father died. He then became head of the firm and carried on the work until shortly after the outbreak of the war. The chief work carried out by him in that year was in connexion with Buckie and other harbours in Banffshire, also the parade and marine drive at Exmouth, and his duties as engineer to the Royal National Lifeboat Institution. In April 1915 he received a Commission as Sub-Lieutenant in the Royal Naval Division, but at the request of the Admiralty he shortly transferred to the Royal Naval Air Service for balloon work, with which he was well acquainted, owing to his pre-war experience in a Territorial Balloon Company. He went immediately to Gallipoli with a kite-balloon section, and during the campaign he was given command of the section and promoted to Lieutenant. On his return to England in April 1916 he was lent temporarily to the Aerial Construction Corps and given command of a camp. Early in 1917 he again went to the Eastern Mediterranean, and when there transferred to the aeroplane branch of the service. In September he was promoted to Flight-Commander. His death took place from an aeroplane accident on 10th December 1917, at the age of thirty-one. He was

* For Memoir, *see* Proceedings, I.Mech.E., 1913, page 978.

elected a Graduate of this Institution in 1907, and an Associate Member in 1912.

SIDNEY HOWARD FARRAR was born at Chatteris, Cambridgeshire, on 15th November 1856. He was educated at Bedford Public School, and in Germany and Switzerland. His apprenticeship was served in the engineering works of his uncles, James and Frederick Howard, of Bedford, and he subsequently travelled on their behalf, in the "Seventies," on constructional work in France, Germany, Austria, Roumania, and Russia. In 1876 he went to South Africa, and became a partner in the firm of Howard Farrar and Co., engineers, of Port Elizabeth and subsequently of Johannesburg, constructors of mining and general machinery. From 1887 onwards he acted as consulting engineer to various mines on the Lydenburg Gold Fields, and from 1889 as consulting engineer for construction to the following Mining Companies: Henry Nourse, Jumpers, Simmer and Jack, United Langlaagte, Geldenhuis Estate, Nooitgedacht, Klerksdorp, New Kleinfontein, Witwatersrand, East Rand Proprietary Mines, and several other companies. He had resided in England for the last twenty years, and was head of the firm of Farrar Brothers, of London. His death took place at his residence at Ascot, on 12th September 1917, in his sixty-first year. He was elected a Member of this Institution in 1881.

Engineer-Commander WILLIAM BRASIER HALL, R.N., was born at Leeds on 13th February 1875. His early education was received privately, after which he went to Torbay College, Torquay. In 1890 he entered the Royal Naval Engineering College, Devonport, and was rated probationary assistant engineer in July 1894. He then attended the course of instruction at the Royal Naval College, Greenwich, until July 1895, when he obtained a first-class certificate, and was employed in the Fleet Reserve, at Devonport for a few months. From March 1896 until August 1899 he served as assistant engineer in H.M.S. "Impérieuse," flagship of the Pacific Station, and then went to the Admiralty as Engineer Assistant from 1901 to 1904. As Engineer-Lieutenant

he was appointed Assistant to the Engineer-Commander on the Staff of the Rear-Admiral commanding the Second Cruiser Squadron, during the visit of this squadron to the United States 1905 to 1907. In 1910 he was sent to join H.M.S. "Fox" on the East Indies Station, and for services at the Persian Gulf he was awarded a medal. At that time also he received his promotion to Engineer-Commander. During the early days of the War, his ship took part in the bombardment of the German batteries on the Belgian Coast, and later on he served throughout the Dardanelles campaign. In the autumn of 1913, he was taken ill whilst serving in the Mediterranean and came home with his ship, H.M.S. "Venerable," some months later. Whilst temporarily relieving another officer for a few weeks he became too seriously ill to remain on duty and was invalided. His death took place at Stonehouse, Glos., on 23rd September 1917, in his forty-third year. He was elected a Graduate of this Institution in 1895, and a Member in 1900.

Lieutenant CHARLES LYSAGHT BRUCE HEWSON, R.E., second son of the late George Hewson, D.L., of Ennismore, Co. Kerry, was born on 1st September 1881. He was educated at schools at Clifton and Tipperary, and in July 1899 he began an apprenticeship at the locomotive shops of the London and North Western Railway, Crewe. During that period he also studied at the Crewe Mechanics' Institute. On leaving in 1903 he went as assistant in the Running Superintendent's Office of the Great Southern and Western Railway, Ireland, but had to leave a few months later owing to serious illness. In May 1905 he went to Egypt, being appointed assistant and district locomotive superintendent on the Sudan Railways during the construction of the Nile to Red Sea Railway. On the completion of this railway in September 1907 he was appointed junior assistant locomotive superintendent to the Government Railways of Southern Nigeria, and in July 1910 he took charge of the locomotive, carriage and wagon shops at Lagos during the absence of the works manager. Subsequently he became District Locomotive Superintendent of

the Olokemeji-Jebba Division. In 1914, shortly after the commencement of the Cameroons Campaign, he was commissioned Lieutenant, and attached to the Royal Engineers, and the railway contingent under his command did excellent work in repairing the railways and locomotives, being mentioned by General Cunliffe in his dispatches. He was invalided from Nigeria, after two months in hospital, from fever contracted in the German Cameroons, and died on the voyage home on 12th April 1917, in his thirty-sixth year. He became an Associate Member of this Institution in 1908, and a Member in 1911.

Stephen Dewar Holden was born at Saltney, Cheshire, on 23rd August 1870, being the youngest son of Mr. James Holden, formerly Locomotive Superintendent of the Great Eastern Railway. His early education was received privately, after which he went to University College School, London. In 1886 he began a pupilage of four years under his father at the locomotive, carriage and wagon works of the Great Eastern Railway, Stratford, and during this period he also studied in the evenings at University College. Subsequently he spent 18 months in the drawing office, and six months as inspector of the running department. He then acted as assistant to the London District Locomotive Superintendent, and in October 1892 was appointed Suburban District Locomotive Superintendent, being transferred to the Ipswich District two years later. In July 1897 he returned to London as District Locomotive Superintendent, and successively became Chief of Running Department, Assistant Locomotive Superintendent, and Locomotive Superintendent, to which post he was appointed in January 1908. This position he held until 1912, when he retired. His death took place at Rochester on 7th February 1918, at the age of forty-seven. He was elected a Member of this Institution in 1910.

Richard Montague Luke was born at Plymouth on 17th January 1881. He was educated at Hoe Grammar School, and, on the completion of his articles with Mr. R. H. Worth, was engaged

on behalf of the contractors at Pembroke Dock, after which he was associated with Mr. H. V. Prigg in constructing the Victoria wharves and tramways at Devonport. About fifteen years ago he started in practice for himself, and soon gained a large connexion. At the time he was overtaken by illness in 1914, he was engaged upon plans for two separate China Clay Companies upon Bodmin Moors, Cornwall, also for waterworks at Combemartin, near Ilfracombe, and sewage and water schemes at Rock, near Padstow, and had just completed waterworks at Silverton, Devon. His death took place in Plymouth, on 15th August 1917, in his thirty-seventh year. He was elected an Associate Member of this Institution in 1904.

James Compton Merryweather was born at Clapham, London, on 12th March 1840. He was educated at Chatham House, Ramsgate, and began his engineering training at the Wolverton Works of the London and North Western Railway. On leaving Wolverton he spent a short time with the firm of McGlashan and Co., coppersmiths, in which he became a partner, but in 1864, owing to the increase in the work at Long Acre, and the failing health of his elder brother Richard, he joined his father in the fire-engine business. He at first took over the control of the coppersmiths' department at Lambeth which prospered exceedingly, and at the same time he was interested in and had much to do, in conjunction with his brother Richard, with the introduction of steam fire-engines. A few years later, owing to the death of his father and the retirement of his brother Richard, he became head of the firm. In collaboration with his brother Henry, he was chiefly responsible for the development of steam tramway-engines, of which a description was given in the discussion on A. Mallet's Paper * on "Mechanical Traction upon Tramways"; and under his direction, the firm in recent years acquired world-wide renown as pioneers of the motor fire-engine industry, the first engine of this type being placed on the road in 1899. He was the author of two standard works, the

* Proceedings, I.Mech.E., 1878, pp. 411-420.

"Fire-Brigade Handbook" and "Fire Protection of Mansions," and was associated with practically all the improvements in fire-extinguishing methods during the past 50 years. Some years ago he established the first weaving shop for the manufacture of canvas hose in London. His death took place at his residence in Whitehall Court, Westminster, on 24th November 1917, at the age of seventy-seven. He became a Member of this Institution in 1875.

Serjeant **REGINALD JOHN SPINK, Canadian Engineers,** was born at Leeds on 30th April 1887. His scholastic education was received in his native city, and at the age of fifteen he began a four-years' apprenticeship at the works of Messrs. Kitson and Co., Leeds. During that period he attended the evening courses at the Technical School and at Leeds University. On the completion of his apprenticeship in 1906 he became a junior draughtsman at the works of Messrs. E. Green and Son, Wakefield, and in the following year he was sent to Germany to open a branch drawing office with the firm's German Co. at Cologne. Having worked there for over three years, he returned to England in December 1910, and was engaged as clerk of works in charge of the erection of two waste-heat stations in Middlesbrough. In 1912 he went to Canada and became mechanical engineer in the office of a Patent Attorney in Vancouver. In 1915 he joined the Army, subsequently becoming Serjeant in the Canadian Engineers, and while holding this rank he was killed in action in Flanders on 21st October 1917, at the age of thirty. He was elected a Graduate of this Institution in 1912, and an Associate Member in 1915.

CECIL WATSON was born at Tottenham on 31st December 1874, and received his early education at the local Grammar School. He began his apprenticeship of four years in 1891 at the locomotive works of Messrs. Dübs and Co., Glasgow, and went through the shops and drawing office. During this period he also attended evening classes at the Glasgow Technical College, and on the completion of his term he went for two years as an improver in the engineering department of the rubber mills of Messrs. W.

Warne and Co., which was followed by a few months' work in the running sheds of the Great Eastern Railway at Stratford. In June 1899 he was appointed an inspector of railway material in the Sheffield District for Sir A. M. Rendel and Robertson, and four years later he was transferred to the London Office of the firm, becoming Head Inspector in 1905. In September 1909 he was appointed manager and chief engineer to the ABC Coupler, Ltd., and visited India, Burma, Ceylon, Egypt, South America, and Nigeria, on behalf of the Company. Specializing in spring gear, buffing, and coupling equipment for railway rolling stock, he brought out several patents, some of which have been adopted as standards on various railways. He was elected Managing Director to the Company in March 1915. His death took place in London on 29th December 1917, within two days of his forty-third birthday. He was elected a Member of this Institution in 1911.

INDEX.

1918.

January–May.

Abbott, J., elected Associate Member, 208.—Remarks on Employment of Women in Munition Factories, 276.

Accles, W. S., Memoir, 371.

Accounts for 1917, 4, 14–22.

Acland, H. A. D., elected Associate Member, 208.

Adam, W. W., Remarks on Employment of Women in Munition Factories, 309.

Adams, D., Capt., R.G.A., elected Associate Member, 326.—Decease, 326.

Adamson, D., nominated for election as Member of Council, 44.—Seconded adoption of Annual Report, 201.—Presentation of Thomas Hawksley Medal, 202.—Elected Member of Council, 204.

Advisory Committees in India, South Africa, and Australia, 9.

Agricultural Motor-Tractors, *Discussion* on Papers by A. Amos and L. A. Legros, 152.—Burford, H. G., Four-wheel drive; unit principle of construction, 152; locking of differential gear; final drive; braking, 153; research on causes of failure, 154.—Crompton, Col. R. E. B., Thomson's road engines, 155; chain-track problem, 156; chain wear at pin-joints, 157; development of roller chains, 158.—Watson, G., Nut-cracker action of chain-track mechanism, 159; speed of cultivation, 160; position of motor on the land; subsoiling, 161.—Patchell, W. H., Varying sizes of track; speed of ploughing; Thomson engine, 162.—Beaumont, Major E. G., Irreversible type of differential gear, 163.—Baker, P. M., Advantage of electric drive; steering, 164; insistent pressure on soil, 165.—Legros, L. A., Unit principle of construction; final transmission, 165; steering; obsolescence; wear of tyres; steam tractors, 166; insistent load; speed of ploughing, 167; differentials; electric drive, 168.

Communications.—Arnold, A. A., Three chain-tracks advisable, 168; weight of engines, 169.—Feeny, V. F., Chain-tractors in America, 169; acreage ploughed per week, 170.—McLaren, H., Acreage ploughed

per week, 171; effect of heavy tractors in bad weather; heavy *v.* light tractors; agricultural competitions, 173; narrow headlands; ploughing hard clay; double-engine cable system, 174.—Phillips, R. E., Early balanced plough; reduction of headland; slipping of plough, 175; "Hedgeland" double-driving gear; positive-drive differential gear, 176.—Royds, R., Steam-engine tractor, 177.—Spence, W. L., Three types of tractors for working under bad conditions, 178.—Legros, L. A., "Centipede" machine; three chain-tracks for soft ground, 179: weight of motor unimportant; chain-tracks on ordinary roads, 180; record week's ploughing; power per acre varies as the depth, 181; results obtained by various tractors, 182; cost of ploughing, 183; ploughing in a spiral direction, 184; steam-driven machines; light-wheeled tractors, 185; slippery ground, 186.—*Appendix III*: Bates Steel Mule, 187; tabulated details of wheeled tractors, 188-9: four classes of light-wheeled tractors, 191.—Amos, A., Avoidance of diagonal pull of wheels; damage to soil due to pressure of machine, 192; acreage ploughed per week, 193; rapid depreciation of machines, 194; one-way ploughing, 194.

ALLEN, R. W., C.B.E., Remarks on Employment of Women in Munition Factories, 227.

ALLEN, W. H., nominated for re-election as Vice-President, 43.—Re-elected Vice-President, 203.—Remarks on Employment of Women in Munition Factories, 224, 231.

ALLOYS RESEARCH, 6.

AMOS, A., *Paper* on Utility of Motor-Tractors for Tillage Purposes, 47.—Remarks thereon, 192.

ANDERSON, Miss A. M., Remarks on Employment of Women in Munition Factories, 269.

ANDERSON, E. W., Remarks on Employment of Women in Munition Factories, 287.

ANDERSON, F. G., elected Associate Member, 326.

ANNUAL GENERAL MEETING, 1918, Business, 195.

ANNUAL REPORT OF COUNCIL, 1. *See* Council, Annual Report.

APPLETON, S., elected Associate Member, 326.

ARKWRIGHT, B. J., Decease, 3.

ARMSTRONG, P. T., Lieut., R.N.V.R., Decease, 3.

ARNOLD, A. A., Remarks on Agricultural Motor-Tractors, 168.

ARTHUR, H. H., Associate Member transferred to Member, 196.

ASH, S. H., Major, R.E., elected Associate Member, 208.

ASPINALL, Sir J. A. F., Knighthood, 2.

ATCHISON, C. C., elected Member, 325.

ATTACK, A. M., elected Associate Member, 208.

Auditor, Appointment, 205.
Austin, Sir H., K.B.E., elected Member, 207.—Remarks on Employment of Women in Munition Factories, 266, 278.
Ayres, G. H., elected Associate Member, 208.

Bailey, J., elected Associate Member, 208.
Baker, J. A., Lieut., A.S.C., elected Associate Member, 208.
Baker, P. M., Remarks on Agricultural Motor-Tractors, 164.
Ball, E. B., Associate Member transferred to Member, 196.
Banks, S. J., elected Associate Member, 326.
Barnes, E. E., Capt., R.E., Memoir, 371.
Barnes, W., elected Member, 207.
Barrow, J., Memoir, 372.
Barry, Sir J. W., K.C.B., nominated for re-election as Member of Council, 44.—Decease, 195.—Memoir, 372.
Barstow, M. W., Lieut., R.G.A., Decease, 3.
Beacham, T. E., Lieut., A.O.D., elected Associate Member, 326.
Beaumont, E. G., Major, A.S.C., Remarks on Agricultural Motor-Tractors, 163.
Beilken, B. J., Decease, 3.
Benevolent Fund, 13.
Berry, W. E., elected Member, 325.
Bettison, F. C., Associate Member transferred to Member, 45.
Beynon, H., Associate Member transferred to Member, 196.
Binks, W. A., Remarks on Employment of Women in Munition Factories, 293.
Binnie, Sir A. R., Decease, 3.
Bircham, F. R. S., Temp. Com., R.N.V.R., elected Member, 207.
Birmingham Meeting, 1918, 329.
Blaikie, W. S., elected Associate Member, 326.
Blane, W., Commandership of Order of British Empire, 2.
Booth, J. W., elected Member, 325.
Boyd, J., elected Associate Member, 326.
Boyd, W., Memoir, 375.
Boyelle-Morin Apparatus for testing Hardness of Metals, 331.
Bramwell, E. C., elected Associate Member, 326.
Brocklehurst, H. C., Associate Member transferred to Member, 328.
Broughall, E. H., elected Member, 325.
Brown, G. W., elected Associate Member, 208.
Brown, J. P., Associate Member transferred to Member, 45.—Remarks on Employment of Women in Munition Factories, 317.
Brown, T. A., elected Associate Member, 208.
Browne, Sir B. C., Decease, 3.
Bryan Donkin Fund, Accounts, 21.—Regulations, 25.

BUCHANAN, JAMES, Decease, 3.—Memoir, 375.
BUCHANAN, JOHN, elected Associate Member, 208.
BUCKHAM, Sir G. T., Knighthood, 2.
BUCKTON, A. S., Capt., R.G.A., Decease, 3.
BUDGE, J., Associate Member transferred to Member, 196.
BURFORD, H. G., Remarks on Agricultural Motor-Tractors, 152.
BURNESS, J. Y., elected Associate Member, 208.
BURROWS, S. H., elected Member, 207.
BUTLER, J., Decease, 3.
BUTLER, W., elected Associate Member, 326.
BUTTERWORTH, J., Remarks on Employment of Women in Munition Factories, 307.
BUTTERWORTH, J. A., elected Associate Member, 326.

CALCUTTA AND DISTRICT SECTION, Meetings in abeyance, 11.
CALISCH, L., elected Associate Member, 326.
CALLENDAR, H. L., presentation of Thomas Hawksley Medal, 202.
CAMERON, A., 2nd Lieut., R.E., elected Associate Member, 326.
CAMPBELL, A., Decease, 3.—Memoir, 375.
CARRINGTON, H., elected Associate Member, 326.
CARRUTHERS, J., Lieut., elected Member, 207.
CARTER, Sir G. J., Knight Commandership of Order of British Empire, 2.
CASSELLS, J. G., elected Associate Member, 208.
CASSIE, G. J., elected Associate Member, 326.
CATERPILLAR TRACTORS, 77, &c. *See* Traction on bad Roads or Land.
CENSOR and rejection of Paper, 210.
CHAIN-TRACK TRACTORS, 77. *See* Traction on bad Roads or Land.
CHALMERS, J. R., Decease, 3.
CHALONER, J. L., 2nd Lieut., R.E., elected Associate Member, 326.
CHARLESWORTH, S., Decease, 3.
CHARNOCK, W. C., elected Associate Member, 326.
CHIVERS, F. E., Decease, 3.—Memoir, 376.
CHORLTON, A. E. L., Commandership of Order of British Empire, 2.
CHRISTIANSEN, A. G., Decease, 3.
CLERK, Sir D., Knight Commandership of Order of British Empire, 2.
CHURCHMAN, H., Sub.-Lieut., R.N.V.R., elected Graduate, 209.
CODDINGTON, Sir W., Bart., Memoir, 377.
COLLEY, L. J. St. J., Major, R.E., elected Member, 207.
COLLINS, H., elected Associate Member, 326.
COOKE, C. J. B., C.B.E., Remarks on Employment of Women in Munition Factories, 318.—*Communication* on Boyelle-Morin Apparatus for Testing Hardness of Metals, 331.

Cooke, G. W., Remarks on Employment of Women in Munition Factories, 313.
Coombs, R. L., Capt., R.F.A., elected Associate Member, 326.
Cormack, Hon. Lt. Col. J. D., Companionship of Order of St. Michael and St. George, 2.
Cornish, E., Eng. Capt., R.N., Decease, 3.—Memoir, 378.
Council, Annual Report, 1.—Number of Members, &c., 1.—Royal Honours, 2.—Deceases, 3-4.—Financial Statement, 4, 14-22.—Members on Active Service, 5.—Employment after the War, 5.—Thomas Hawksley Gold Medal Award, 6.—Research Grants: Alloys; Steam-Nozzles; Hardness Tests, 6; Wire Ropes, 7.—Williamson Grant for Research, 7.—T. Bernard Hall Prize, 8.—Training of Engineers, 8.—Institution Examinations, 9.—Indian and South African Advisory Committees, 9.—Meetings and Papers, 9.—Local Correspondents and Meetings, 10.—Calcutta and District Section, 11.—Graduates' Association, 11.—Additions to Library, 11, 28-41. Representation on other Organizations, 11.—Compulsory adoption of Metric System, 12.—Technical Literature for British Prisoners of War, 12.—Benevolent Fund, 13.
Longridge, M., Motion for adoption of Report, 196.—Adamson, D., seconded adoption of Report, 201.—Report adopted, 202.
Council, Retiring List, and Nominations for 1918, 43.—Election, 203.—For 1918, 204.
Cousin, A. N., Capt., Memoir, 378.
Crane, R., re-appointed to audit Institution Accounts, 205.
Craven, J. E. H., Decease, 3.
Creak, R. B., Remarks on Employment of Women in Munition Factories, 225.
Creese, L. F., Eng. Lieut., R.N.V.R., elected Graduate, 209.
Crewe, W. A., elected Associate Member, 208.
Crichton, J. A., Major, R.E., Decease, 3.
Critchley, H. L., M.B.E., Associate Member transferred to Member, 328.
Crofton, E. V. M., Lieut., R.E., Decease, 3.
Crompton, R. E. B., Col., R.E., Remarks on Agricultural Motor-Tractors, 151, 162.—Moved reappointment of Auditor, 205.
Crosby, R., elected Associate Member, 326.
Cuming, G., Officer of Order of British Empire, 2.

Dancaster, H. W., elected Associate Member, 326.
Daubeny, E. C., elected Member, 325.
Davey, T. F., elected Graduate, 327.
Davies, S. J., Remarks on Employment of Women in Munition Factories, 296.
Davis, C. G., elected Member, 207.

DECEASES of members during 1917, 3.
DEFRIES, W., Remarks on Employment of Women in Munition Factories, 290.
DERBYSHIRE, R. K., elected Associate Member, 208.
DESPAIGNE, H., elected Member, 207.
DEVINE, D., elected Associate Member, 326.
DICKSON, W. M., elected Member, 325.
DIGBY, C., Associate Member transferred to Member, 328.
DISTINGUISHED SERVICE ORDER, List of Awards, 2.
DIXON, F. J., elected Member, 325.
DOLBY, E. R., seconded reappointment of Auditor, 205.—Remarks on Employment of Women in Munition Factories, 281.
DONKIN FUND (BRYAN), Accounts, 21.—Regulations, 25.
DOUGLAS, C. H., Major, R.F.C., elected Member, 207.
DOUGLAS, J. T., elected Member, 325.
DOUGLASS, P. C. D., Flight-Com., Decease, 3.—Memoir, 379.
DRAYSON, D., elected Associate Member, 326.
DRIVER, J. F., Remarks on Employment of Women in Munition Factories, 318.—Elected Associate Member, 326.
DURSTON, Sir A. J., K.C.B., Eng. Vice-Admiral, Decease, 3.

EADY, R. G., elected Associate Member, 326.
EAVES, W., elected Member, 207.
EDWARDS, A. E. A., Remarks on Women Workers in Engineering Factories, 301.
EDWARDS, C. A., awarded Sir Robert Hadfield Prize, 203.—*Paper* on a Law governing the Resistance to Penetration of Metals, and a new Hardness Scale, 335.
EDWARDS, G. H., elected Associate Member, 208.
ELECTION, Council, 203.—Members, &c., 207, 325.
ELLISON, J. M., Lieut., R.F.A., elected Associate Member, 326.
EMPLOYMENT of members after the War, 5.
EMPLOYMENT OF WOMEN IN MUNITION FACTORIES, *Paper* by Miss O. E. Monkhouse, M.B.E., 213.—Introduction, 213.—The employer; the skilled man; the unskilled woman, 214.—How women have reached their present skill, 216.—Training of women workers; women trained in works in a separate shop, 216.—Overcoming of incredulity on part of management, 217.—Other successful methods of training women workers, 217.—Characteristics of women, 218.—Shop organization, 218.—Choice of labour, 218.—Ordinary Labour, 219.—Welfare; effect of welfare on production, 219; welfare on the race, 220.—Hours of work, 220.

Discussion on 15th March 1918.—Monkhouse, O. E., Paper unofficial, 221.—Longridge, M., Effect of munition work on women's welfare, 221.

—Wicksteed, C., Experience of women labour and nature of work, 223: bad time-keeping, 224; importance of skilled tool-setter; women suitable as tool-attendants but not as engineers; future unemployment, 225.—Creak, R. B., Value of training schools; shorter shifts advisable, 226.—Hartness, J., Greeting from A.S.M.E., 226; percentage of men leaving shops during year, 227.—Allen, R. W., Success depends on sympathy of employer, 227; women and engineering training, 228; types of women workers, 229.—Rankine, W., Work of training centres, 230.—Allen, W. H., Necessity for good supervisor, 231; women employment after the war, 232; women's welfare, 233.—Legros, L. A., Type punches cut by women, 234; wire-stay work; rapid speed obtained on shells, 236: high technical work of women; intensive training, 237; care required in selecting women workers, 238.

Discussion on 3rd May.—Austin, Sir H., Dilution should be adopted by all manufacturers, 266; women labour after the war, 267.—Molesworth, Sir G. L., Restriction of output, 268; increased output by women, 269.—Anderson, Miss A. M., Safeguarding labour, 269; extension of women's work, 270.—Proctor, C. F., Success of women's work in incandescent lamp making, 270; co-operation of women improves men's status, 272. — Abbott, J., Necessity for woman supervisors and welfare workers, 276.—Smith, Major S. H., Dilution of labour provided for in design department, 277; employment of women benefits the family, 277.—Reavell, W., Women excel in machining rather than in fitting work, 279; production of women in fuse-shop exceeded that of men, 280; adaptability and bravery of women, 280.—Dolby, E. R., Definition of "assembling" and "fitting," 281.—Monkhouse, Miss O. E., Domestic claims prevent women from becoming engineers, 281; welfare work for men needed, 282; explanation of technicalities required, 283.—Morgan, B. H., Employment of women as a war measure, 283; loyal co-operation of trade unionists, 284; efficiency of production depends on welfare of workers, 284.

Discussion in Birmingham, 9th May.—Muntz, Sir G. A., Women supervisors necessary, 285; proposed Committee of Inquiry, 286.—Anderson, E. W., Women labour on small-arms ammunition manufacture, 287. — Nasmith, J., Armature winding by women; excellence of repetition work, 288.—Fearn, J., Experience at B. S. A. Co., 288; objections to suggested Inquiry, 290.—Defries, W., Greater employment of women after the War, 290. — Parsons, R. H., Organization of engineering work, 292.—Binks, W. A., Difficulties of Inquiry, 293; women deficient in initiative, 294; gauge-making, 295.—Davies, S. J., Tuition in use of gauges, 296.—Morgan, B. H., Scope of suggested Inquiry, 296; Paper deals with dilution during the War, 297;

quick training of women; probable long duration of the War, 298; labour dilution standards, 299. — Muntz, Sir G. A., Patriotism of women workers, 301: thanks for loan of Meeting Hall, 302.

Discussion in Manchester, 10th May.—Hopkinson, E., Unusual type of Papers, 302; labour costs required, 303; armature winding, 304.—Windeler, G. E., Success of women workers in manufacture of engines, 304; crane operations, 306.—Butterworth, J., Absence of discipline among male workers, 307; abolition of old objectionable practices, 308.—Adam, W. W., Advantageous employment of women, 309.—Smith, H., Girls on electrical work before the War, 310; women are not good time-keepers; difficulties of using adapted machinery, 311.—Howell, A. E., Advantages and drawbacks of female labour, 312.—Cooke, G. W., Comparative work of men and women, 313.—Morgan, B. H., Heavy work unsuitable, 313; time-keeping; standards of work, 314; gun dilution standards; suggested Committee of Inquiry, 315.

Communications.—Longridge, M., Expediency of women labour, 317.—Brown, J. P., Satisfactory experience of women's work, 317.—Cooke, C. J. B., Work for maimed soldiers, 311.—Driver, J. F., Training of women workers at Loughborough, 318.—Lewis, Miss G. T., Intensive training of women, 319.—Sheret, D. A., Work for educated women in future, 322.—Warneford, W. W. H., Employment of discharged soldiers, 323.—Morgan, B. H., Examples of Labour Efficiency and Dilution Standards, 323.

ENGINEERING APPRENTICES IN AMERICA, 8.

ENGINEERING FACTORIES, Utilization of Labour in, 239.

ENGINEERING TRAINING, Conference, 8.

ERICHSEN, F. O., Decease, 3.

ERMEN, B. G., Decease, 3.

EWING, Sir J. A., K.C.B., resigned Membership of Council, 44.

EXAMINATIONS, 9.

FARRAR, S. H., Decease, 3.—Memoir, 380.

FEARN, J., Remarks on Employment of Women in Munition Factories, 288.—Elected Associate Member, 326.

FEENY, V. F., Remarks on Agricultural Motor-Tractors, 169.

FILDES, J. H. S., elected Associate Member, 326.

FIRTH, W., elected Member, 207.

FLETCHER, T. W., elected Member, 325.

FORD, T. W., Decease, 3.

FORRESTER, H. A., elected Associate, 209.

FORWARD, E. A., Associate Member transferred to Member, 196.

FOWLER, Sir H., K.B.E., Commandership of Order of British Empire, 2.—

Nominated for election as Member of Council, 44.—Elected Member of Council, 204.
Fozard, H. E., elected Associate Member, 326.
Fraser, P., Decease, 3.
Fyffe, A. M., Decease, 3.

Garrett, C. A. B., elected Associate, 327.
Gavin, N. A., Decease, 3.
Géraki, J., elected Member, 207.
Glaser, H., elected Member, 325.
Glass-Hooper, C. T., Examination Prize Award, 9.—Presentation of Prize, 203.
Gough, G. N., elected Associate Member, 208.
Graduates' Association, Meetings in abeyance, 11.
Graham, J. C., Lieut., R.N., Associate Member transferred to Member, 45.
Greenwood, R., elected Associate Member, 326.
Griffith, A. A., Thomas Hawksley Gold Medal Award, 6.—Presentation of Medal, 202.
Griffiths, R. S., Major, R.G.A., Decease, 3.
Griffiths, R. St. A., Capt., R.E., elected Associate Member, 208.
Griggs, W. J., Decease, 3.

Hadfield, Sir R. A., Bart., Baronetcy, 2.
Hadfield Prize Fund (Sir Robert), Accounts, 22.—Conditions of Award, 26.—Award, 203.
Hall, G. S., 2nd Lieut., R.F.C., Decease, 3.
Hall, J. P., Decease, 3.
Hall, O. S., Remarks on Employment of Women in Munition Factories, 310.
Hall, T. B., Prize Fund for Papers, 8.—Accounts, 22.—Conditions of Award, 27.
Hall, W. B., Eng. Com., R.N., Decease, 3.—Memoir, 330.
Handcock, R. H., Lieut., A.O.D., Decease, 3.
Hanton, J. R., elected Associate Member, 326.
Harben, J. E., Lieut., R.E., elected Associate Member, 208.
Hardness of Metals, Boyelle-Morin Apparatus for testing, 331.
Hardness Tests by Impact, 335.—*Paper* on a Law governing the Resistance to Penetration of Metals when tested by Impact with a 10 mm. steel ball; and a new Hardness Scale in Energy Units, by C. A. Edwards and F. W. Willis, 335.—Objections to Brinell method, 336.—Description of apparatus, 338.—Methods of gradually applied load, 342.—Shore's scleroscope, 344; modified form of apparatus, 345; effect of second impact resulting from rebound, 347; experimental results, 347.—

Tabulated values of Constants, 361.—Advantages of dynamic method of testing over that of static load, 362.—Comparison of Brinell, Scleroscope, and Impact Indent, 363.—Rebound experiments from Authors' impact instrument 365.—Conclusions deduced, 367.

Hardness Tests Research, 6.

Harley, G., elected Associate Member, 208.

Hartness, J., Remarks on Employment of Women in Munition Factories, 226.

Harvey, W. C., Lieut., K.R.R., Decease, 3.

Hawes, B. L., elected Associate, 327.

Hawksley, C., Decease, 3.

Hawksley Fund (Thomas), Awards, 6.—Lecture in 1917, 10.—Accounts, 21.—Presentation of Awards, 202.

Hayes, E., Decease, 3.

Hayes, J., Decease, 3.

Hewson, C. L. B., Lieut., R.E., Memoir, 381.

Higgs, P. J., elected Graduate, 327.

Hill, R. A., Decease, 3.

Hodgson, H., elected Associate Member, 208.

Hodgson, W., Major, R.G.A., elected Associate Member, 326.

Holden, S. D., Memoir, 382.

Holman-Hunt, H. L., C.I.E., elected Member, 325.

Honours conferred by The King, 2.

Hooper, E. F., elected Associate, 209.

Hopkinson, Major B., Companionship of Order of St. Michael and St. George, 2.

Hopkinson, E., nominated for election as Member of Council, 44.—Elected Member of Council, 204.—Remarks on Employment of Women in Munition Factories, 302.

Hopkinson, F. A., Decease, 3.

Horton, H., elected Graduate, 209.

Howell, A. E., Remarks on Employment of Women in Munition Factories, 312.

Hoyle, J. R., nominated for re-election as Vice-President, 43.—Re-elected Vice-President, 203.

Impact Tests on Metals, Boyelle-Morin Apparatus, 331.—*See* also Paper by C. A. Edwards and F. W. Willis.

Irwin-Packington, P., Lieut., R.G.A., Associate Member transferred to Member, 196.

Ivatt, H. A., nominated for re-election as Member of Council, 44.—Re-elected Member of Council, 204.

January Meeting, 1918, Business, 43.
Jefferies, H. S., Decease, 3.
Johnson, J. W., Decease, 3.
Jones, F. T., elected Associate Member, 326.
Jones, G. P., Decease, 3.
Jordan, E., Decease, 3.

Kanthack, F. E., Companionship of Order of St. Michael and St. George, 2.
Kempe, I. T., Capt., A.S.C., elected Associate Member, 326.
Kennedy, C., Lieut. R.F.A., Decease, 3.
Kennedy, T., Decease, 3.
King, E. P., elected Associate Member, 208.
Kirby, J. P., Decease, 3.
Knight, R. E., Major, R.E., elected Associate Member, 326.

Laity, H. T., Associate Member transferred to Member, 209.
Lane, F. T., elected Associate Member, 208.
Langdon, D. E., Capt., Decease, 3.
Larke, W. J., Officer of Order of British Empire, 2.
Latham, B., Decease, 4.
Lawrence, J. C. O., elected Associate Member, 326.
Lee, J. A., elected Associate Member, 208.
Leeds Meeting, 1918, 45.
Legros, L. A., *Paper* on Traction on bad Roads or Land, 55.—Remarks thereon, 165, 179:—on Employment of Women in Munition Factories, 234.
Lewis, Miss G. T., Remarks on Employment of Women in Munition Factories, 319.
Library Donations, 11, 28-41.
Lincoln Meeting, 1918, 45.
Local Correspondents, 10.
Lockwood-Bunce, T., M.B.E., Associate Member transferred to Member, 328.
Longhurst, H. A., Decease, 4.
Longridge, M., nominated for re-election as President, 43.—Remarks on Agricultural Motor-Tractors, 54.—Decease of Sir J. Wolfe Barry, K.C.B., 195.—Moved adoption of Annual Report, 196.—Presentation of Thomas Hawksley Gold Medals, 202; and of Examination Prizes, 203.—Re-elected President, 203.—Remarks on re-appointment of Auditor, 205:—on Censoring of B. H. Morgan's Paper, 210:—on Employment of Women in Munition Factories, 221, 317, 328.—Vote of Thanks to Inst. C.E., 328.—Remarks on Boyelle-Morin Apparatus, 329.
Lorrain, J. G., Decease, 4.

Luckett, A. G., elected Associate Member, 326.
Luke, R. M., Decease, 4.—Memoir, 382.
Lyen, O. Y. S., elected Graduate, 209.

MacArthur, W. W., elected Associate Member, 208.
MacKenzie, M. M. H., elected Associate, 209.
McLaren, H., Remarks on Agricultural Motor-Tractors, 170.
McLusky, J. W., elected Associate Member, 208.
Major, C. G., Decease, 4.
Mallet, A., Presentation of Thomas Hawksley Medal, 202.
Manchester Meetings, 1918, 45, 329.
Manisty, H. S., Lieut., R.E., Decease, 4.
March Meeting, 1918, Business, 207.
Marks, Sir G. C., M.P., Commandership of Order of British Empire, 2.
Marris, R. W. H., elected Associate Member, 208.
Marsden, E., Sub.-Lieut., R.N.V.R., elected Graduate, 209.
Martin, W. H., Decease, 4.
Mattock, W. G. H., elected Associate Member, 208.
Maunsell, R. G. F., Capt., R.E., Decease, 4.
Maxted, F. R., elected Associate Member, 326.
May, A. G., elected Associate Member, 208.
May Meeting, 1918, Business, 325.
Mechanical Engineering Research, 7. *See* Piston and Piston-Rings Research.
Meetings, 1918, in London: January, 43.—Annual General, 195.—March, 207.—May, 325:—Birmingham, 329:—Leeds, 45, 182, 191:—Lincoln, 45, 191:—Manchester, 45, 182, 191, 329:—Glasgow, 181, 185, 191.
Memoirs of Members, etc., recently deceased, 371.
Menkens, C., elected Associate Member, 326.
Meredith, P. H., elected Associate Member, 326.
Merryweather, J. C., Decease, 4.—Memoir, 383.
Metric System, Compulsory adoption, 12.
Midgley, H. E., Associate Member transferred to Member, 209.
Military Cross, List of Awards, 2.
Miller, A. S., elected Associate Member, 327.
Milne, W., Decease, 4.
Molesworth, Sir G. L., K.C.I.E., Remarks on Employment of Women in Munition Factories, 268.
Monkhouse, Miss O. E., *Paper* on the Employment of Women in Munition Factories, 213.—Remarks thereon, 221, 281.
Moore, J. E., elected Graduate, 327.

Morgan, B. H., *Paper* on the Efficient Utilization of Labour in Engineering Factories, 239.—Remarks thereon, 283, 296, 313, 323.
Morgan, T. H., elected Associate Member, 208.
Moss, H., Membership of Order of British Empire, 2.
Motor Tractors for Tillage Purposes, *Paper* by A. Amos, 47.—Advantages; factors determining texture or friability of soil, 47.—Power required, 48.—Weight, 49.—Speed, 50.—Wheels and grip, 51.—Turning at headlands, 52; advantages of balanced plough, 53.
Longridge, M., Thanks to Author, 54.
(For *Discussion*, *see* Agricultural Motor Tractors.)
Munition Factories, Employment of Women in, 213. *See* Employment of Women in Munition Factories.—Utilization of Labour in, 239.
Munro, A. R., elected Associate Member, 208.
Muntz, Sir G. A., Bart., Remarks on Employment of Women in Munition Factories, 285, 301.
Murgatroyd, F., elected Member, 208.

Nasmith, J., Remarks on Employment of Women in Munition Factories, 287.
Neill, R., elected Member, 208.
New Scale of Hardness, 335. *See* Hardness Tests by Impact.
Nicholls, J. M., Decease, 4.
Nichols, T. W., elected Member, 208.
Noakes, T. J., Decease, 4.
Noble, G., Lieut., A.O.D., elected Associate Member, 327.
Novelli, M., elected Associate Member, 327.
Nutton, H., elected Associate, 327.

Oram, Eng. Vice-Adm. Sir H. J., K.C.B., nominated for re-election as Member of Council, 44.—Re-elected Member of Council, 204.
Ormesher, A. H., Lieut., elected Associate Member, 208.

Paper rejected by the Censor, 210.
Parkinson, E., Officer of Order of British Empire, 2.
Parsons, B. F., 2nd Lieut., R.F.C., Decease, 4.
Parsons, R. H., Remarks on Employment of Women in Munition Factories, 292.
Patchell, W. H., Remarks on Agricultural Motor-Tractors, 162.
Paulin, G. H., elected Associate Member, 327.
Perry, E. W. F., elected Associate Member, 327.
Phillips, R. E., Remarks on Agricultural Motor-Tractors, 175.
Pilkington, H., Decease, 4.
Pirie, A. H., elected Associate Member, 327.

Piston and Piston-Rings Research, 7.
Pitman, P. H., Associate Member transferred to Member, 45.
Pitt, W., resigned Membership of Council, 44.
Playne, A. C., Eng. Lieut., R.N.R., elected Associate Member, 327.
Polden, F. C., Associate Member transferred to Member, 209.
Pratt, A. C., elected Associate Member, 208.
Proctor, C. F., Remarks on Employment of Women in Munition Factories, 270.

Quelch, A. T., Associate Member transferred to Member, 328.
Quicke, J. H., elected Associate Member, 327.

Radford, R. H., Decease, 4.
Rankine, W., Remarks on Employment of Women in Munition Factories, 229.
Ratcliffe, R. A., elected Associate Member, 208.
Raven, Sir V. L., Knighthood, 2.—Knight Commandership of Order of British Empire, 2.
Reavell, W., Remarks on Employment of Women in Munition Factories, 278.
Reddy, F. H., elected Associate Member, 327.
Reed, F. H., elected Graduate, 327.
Reid, F. H., elected Associate Member, 208.
Report of Council, Annual, 1. *See* Council, Annual Report.
Research: Alloys, 6:—Steam-Nozzles, 6:—Hardness Tests, 6:—Wire Ropes, 7:—Piston and Piston-Rings, 7.
Restler, J. D. K., Lieut.-Commr., R.N.V.R., elected Member, 325.
Restler, J. W., nominated for election as Member of Council, 44.—Elected Member of Council, 204.
Rhodes, J., elected Associate Member, 327.
Richards, F. H., Lieut., R.E., elected Associate Member, 208.
Richards, H. E., elected Associate Member, 209.
Richardson, J. J., elected Associate Member, 209.
Ripper, W., Companionship of Honour, 2.
Robb, H. B., Lieut., A.S.C., Decease, 4.
Roberts, D. E., nominated for election as Member of Council, 44.
Robson, J., elected Associate Member, 327.
Rogerson, H., elected Graduate, 327.
Royds, R., Remarks on Agricultural Motor-Tractors, 177.

Sauvage, E., Presentation of Thomas Hawksley Medal, 202.
Schofield, H., Membership of Order of British Empire, 2.

Scott, D. P., elected Associate Member, 327.
Scott-Robinson, M., elected Member, 208.
Service, W., elected Member, 208.
Sharp, R. G., Decease, 4.
Sheldrick, J. E., elected Graduate, 209.
Shepherd, F. J., Decease, 4.
Sheret, D. A., Remarks on Employment of Women in Munition Factories, 322.
Shroff, A. B., Decease, 4.
Sir Robert Hadfield Prize Fund, Accounts, 22.—Conditions of Award, 26. —Award, 203.
Skerrett, H. N., elected Associate, 327.
Smith, A. R., elected Associate Member, 209.
Smith, H., M.B.E., Remarks on Employment of Women in Munition Factories, 310, 315.
Smith, H. J., elected Member, 208.
Smith, J., Decease, 4.
Smith, Major S. H., Remarks on Employment of Women in Munition Factories, 277.
Spedding, J. J., elected Associate Member, 209.
Spence, J. W., elected Associate Member, 327.
Spence, W. L., Remarks on Agricultural Motor-Tractors, 177.
Spink, R. J., Serj., Decease, 4.—Memoir, 384.
Spooner, G. P., Decease, 4.
Stack, W. A., Capt., elected Associate Member, 327.
Stanley, C., elected Member, 208.
Stanley, E., elected Graduate, 327.
Stansfeld, J., elected Member, 208.
Starley Premium Fund, Accounts, 20.
Steam-Nozzles Research, 6.
Stirling, J., Decease, 4.
Storey, J. E., Decease, 4.
Stork, S. G., elected Associate Member, 327.
Sutherland, K. W., Associate Member transferred to Member, 209.
Swindin, N., elected Associate Member, 209.
Symonds, P. H., Associate Member transferred to Member, 196.
Symons, D. A., Decease, 4.

Tait, E. B., elected Member, 325.
Tanner, W. S., Jun., elected Associate Member, 327.
Taylor, B., elected Associate Member, 327.

TAYLOR, G. I., Thomas Hawksley Gold Medal Award, 6.—Presentation of Thomas Hawksley Medal, 202.

TAYLOR, W., nominated for election as Member of Council, 44.

THOMAS, H. E. R., elected Associate Member, 209.

THOMAS, L. H., elected Associate Member, 209.

THOMAS, R. B., Decease, 4.

THOMAS HAWKSLEY FUND, Awards, 6.—Lecture in 1917, 10.—Accounts, 21.—Presentation of Awards, 202.

THORNE, G. S., Capt., R.F.C., Decease, 4.

THWAITES, R. A. S., elected Associate Member, 209.

TOWNHILL, W., Decease, 4.

TRACTION ON BAD ROADS OR LAND, *Paper* by L. A. Legros, 55.—Varied problems, 55.—Renard road train, 56.—PART I: Four-Wheel Drive, 56; four-wheel steering, 57; four-wheel braking, 59; four-wheel driving, 60; automatic differential locking gears, 61; four-wheel drive, front steering, 66; four-wheel steering, 67; independent drive with four-wheel steering, 71; applications of four-wheel drive to bad roads, 76.—PART II: Chain-Track Tractors, 77; classification, 81; four methods of springing, 83; truck-frames and track-frame connexions, 86; driving-gear, 88; chain-tracks, 89; track shoes, 95; engines, 96; ignition and starting, 97; radiators, 98; speed of tractors, 98; drawbar pull, 99; climbing power, 100: drawbar connexion, 101.—Leading features of tractors.—Phœnix log-hauler, 102.—Phœnix centiped truck, 104; Allis-Chalmers tractor-truck, 104; Holt caterpillar, 105; Clayton tractor, 112; C. L. Best track-layer, 118; Bullock creeping-grip tractor, 122; Austin tractors, 123; Burford-Cleveland tractor, 123; Killen-Strait tractor, 124; Yuba ball-tread tractor, 126; Martin's tractor, 127; Wolseley motor-sleigh, 127.—Mixed Tractors: Lefebvre tractor, 129.—Applications of chain-track traction, 130; chain-track haulage wagons, 132; Parsons excavators, 132; Austin drainage excavators, 133; back fillers, 134.—Conclusions, 135.—Appendix I: Historical Note, 136.—Appendix II: Authorities consulted, 143.—Table 1: Four-wheel driven vehicles; engine, speeds, brakes, &c., 144.—Table 2: Chain-track tractors, 146.

(For *Discussion*, *see* AGRICULTURAL MOTOR-TRACTORS.)

TRACTORS FOR TILLAGE PURPOSES, 47. *See* Motor-Tractors for Tillage Purposes.

TRAINING OF ENGINEERS, Conference, 8.

TRANSFERENCES of Associate Members, &c., to Members, 45, 196, 209, 327.

TREMEARNE, W. C., 2nd Lieut., Decease, 4.

TROUP, J. D., Lieut., R.F.C., elected Member, 325.

TURNER, W. C., elected Associate Member, 209.

Vickers, G. B., elected Associate Member, 209.
Vote of Thanks to Inst. C.E., 328.
Vowles, W. H. P., elected Associate Member, 327.

Walker, E. G., Lieut., R.N.V.R., Associate Member transferred to Member, 196.
Walker, R. H., Lieut., Decease, 4.
Walker, W. P., Associate Member transferred to Member, 328.
War Prisoners (British), Technical literature and Examinations for, 12.
Ward, A. K., elected Associate Member, 209.
Warneford, W. W. H., Remarks on Employment of Women in Munition Factories, 323.
Warren, C. T., elected Associate Member, 327.
Water Arbitration Prize Fund, Accounts, 20.—Regulations, 24.
Watson, C., Decease, 4.—Memoir, 384.
Watson, G., Remarks on Agricultural Motor-Tractors, 159.
Webster, N. J., elected Associate Member, 327.
Weir, Sir W., Knighthood, 2.
Westmacott, P. G. B., Decease, 4.
Whipple, R. S., Presentation of Thomas Hawksley Medal, 202.
Wicksteed, C., Remarks on Employment of Women in Munition Factories, 223.
Wildy, E. L., elected Associate Member, 209.
Willans Premium Fund, Accounts, 20.—Declaration of Trust, 23.
Williams, A. L., Examination Prize Award, 9.—Presentation of Prize, 203.
Williams, V. S., elected Associate Member, 327.
Williamson, R., nominated for election as Member of Council, 44.—Elected Member of Council, 204.
Willis, F. W., awarded Sir Robert Hadfield Prize, 203.—*Paper* on a Law governing the Resistance to Penetration of Metals, and a new Hardness Scale, 335.
Wilson, N., Lt. Col., R.E., Companionship of the Order of St. Michael and St. George, 2.
Wilson, P. H., Capt., R.E., elected Associate Member, 327.
Wiltshire, G. H., elected Graduate, 327.
Windeler, G. E., Remarks on Employment of Women in Munition Factories, 304.
Wire-Ropes Research, 7.
Wolsey, G., 2nd Lieut., R.E., elected Associate Member, 209.
Women Employees in Munition Factories, 213. *See* Employment of Women in Munition Factories.
Women Workers in Engineering Factories, *Paper* on the Efficient

Utilization of Labour in Engineering Factories, by B. H. Morgan, 239. —Reason for employment of women; Crayford Agreement, 240; the Treasury Agreement, 241; instructions to Controlled Establishments, 242.—Objections to the scheme, 243.—Employers' difficulties in introducing women labour, 245.—Considerations regarding employment of women, 246.—Inequalities of dilution, 248.—Ministerial action, 248. —Dilution standards, 249.—Requirements of an ideal dilution system, 252; labour efficiency standard, 253; dilution standard, 253.—Dilution and industrial efficiency, 253.—Determination and application of standards, 254. — Difficulties due to variety of outputs, 256.— Standardization methods of manufacture, 256. — Appendix on Employment of Women: Construction, 258; War Work, 262; Operating Work, non-constructional, 263; Miscellaneous Processes, 264.

(For DISCUSSION, *see* Employment of Women in Munition Factories.)

WOOD, A. J., elected Associate Member, 209.

WORSSAM, L. H., Decease, 4.

YAPP, R. H., elected Associate Member, 209.

YOUNG, E. C., elected Associate Member, 209.

Fig. 7. *Dorr-Miller Automatic-locking Differential.*

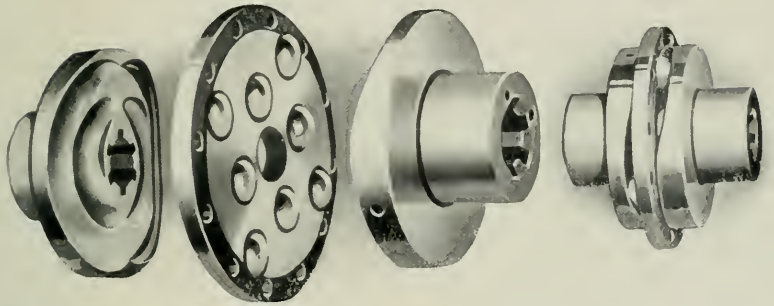


Fig. 10. *F.W.D. Centre Differential and Locking-levers.*

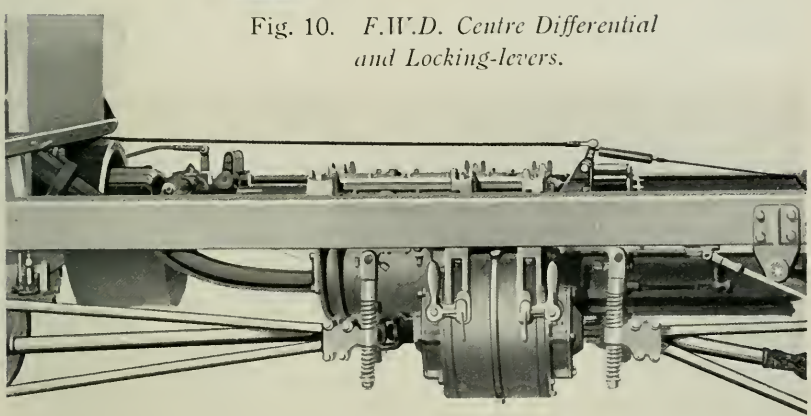
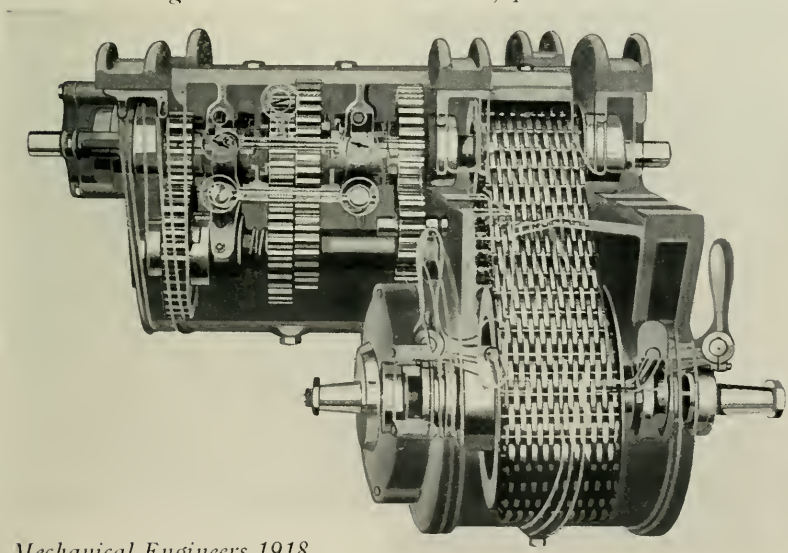


Fig. 11. *F.W.D. Transmission ; phantom view.*



F. W. D.

Fig. 12. *3-ton Chassis.*

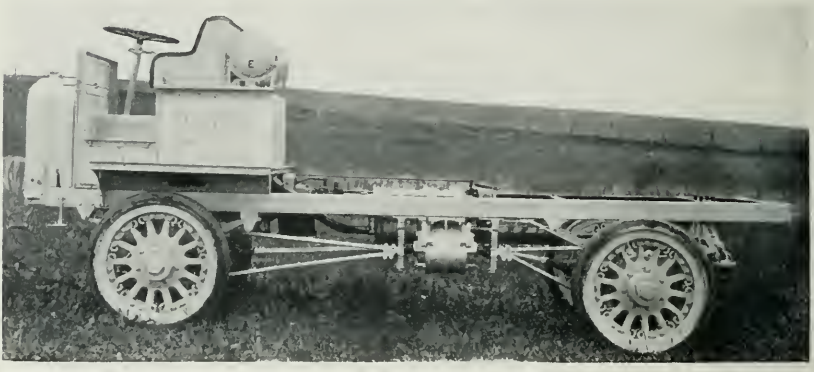
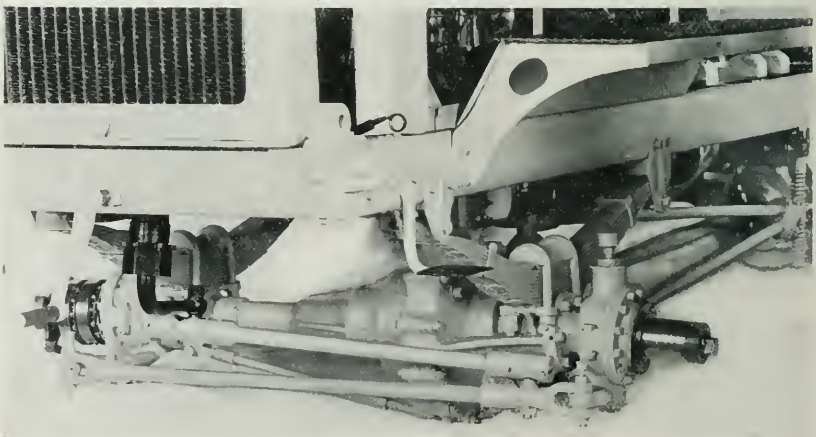


Fig. 13. *Side-tip Wagon.*

Fig. 14. *Front Axle.*



F.W.D. 3-ton Truck.

Fig. 15. *Carrying Ore over Sand, Utah.*

Fig. 16. *On a Sea of Alkali-mud, (70 miles from base).*

Fig. 17. *Hauling Industrial Railway Cars.*

Fig. 18. *F.W.D. End-tip Wagon.*

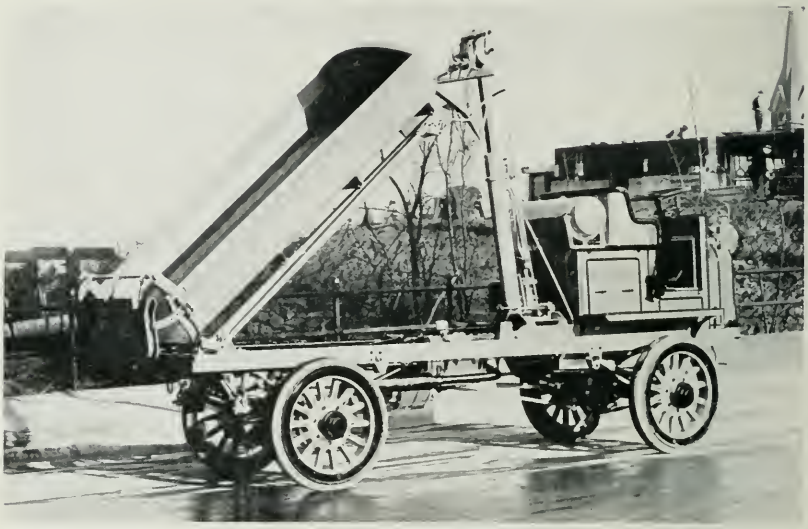


Fig. 23. *Walter Super-quad ; inverted view—wheels straight.*

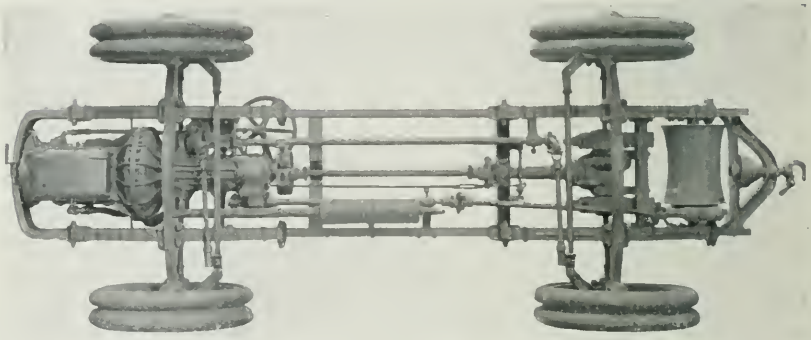


Fig. 24. *Walter Super-quad ; inverted view—wheels locked.*

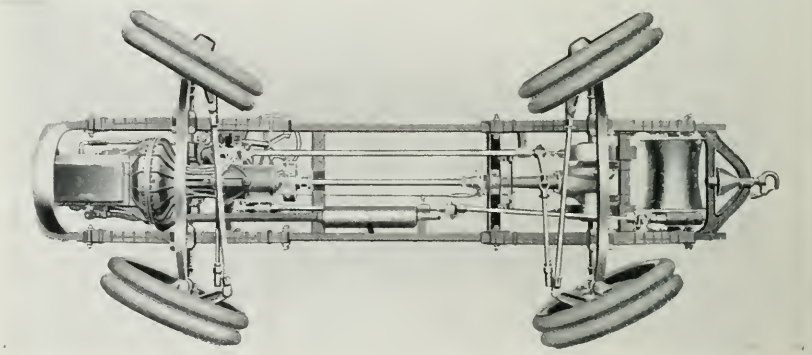
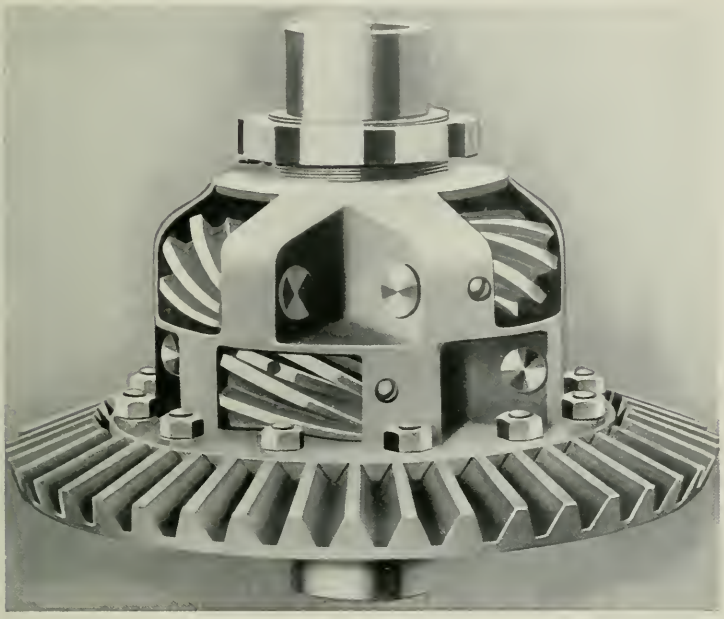


Fig. 25. *Walter Automatic-locking Differential.*



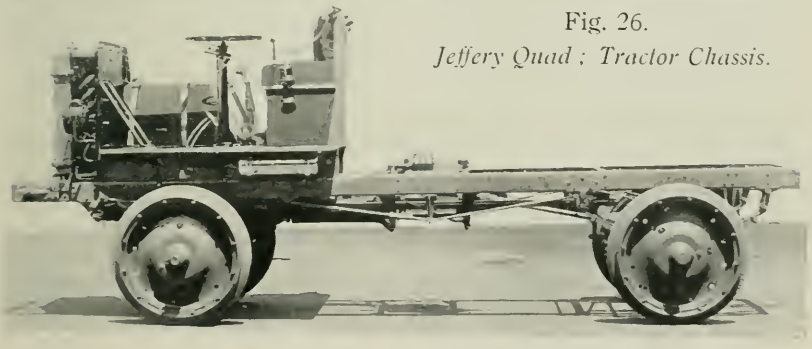
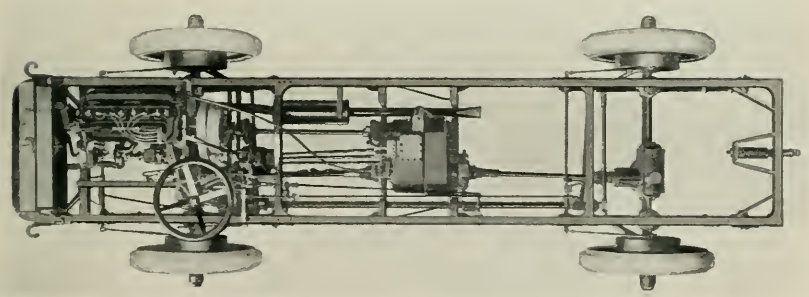


Fig. 26.
Jeffery Quad ; Tractor Chassis.

Fig. 27. *Jeffery Quad ; plan view of Chassis.*



Couple-gear.

Fig. 31. *Wheel, complete but without tyre.*

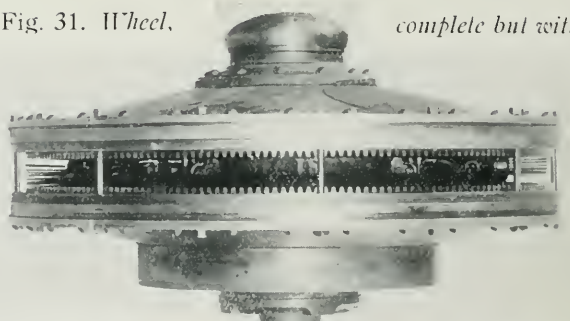


Fig. 32. *Wheel, details showing Motor.*

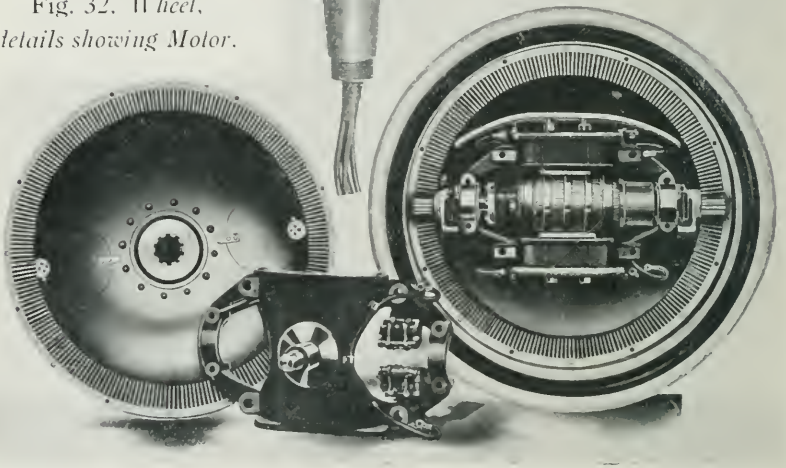
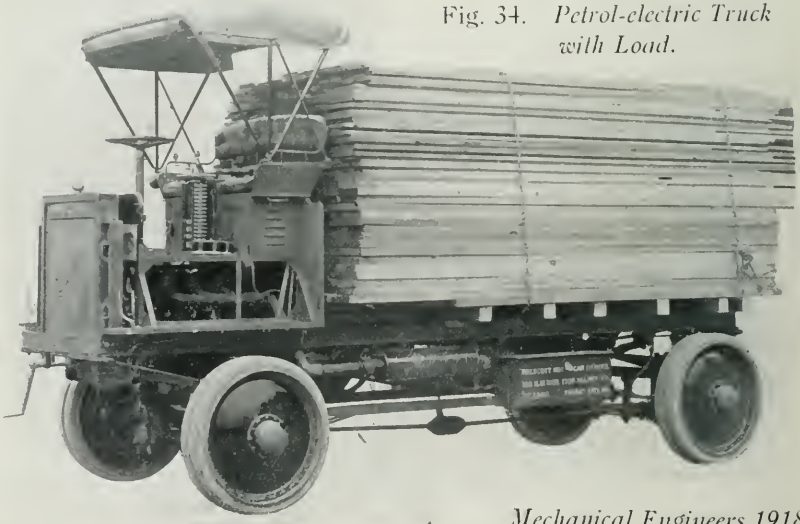


Fig. 34. *Petrol-electric Truck with Load.*



couple-gear.

Fig. 35.
Petrol-electric Truck, Power Plant.

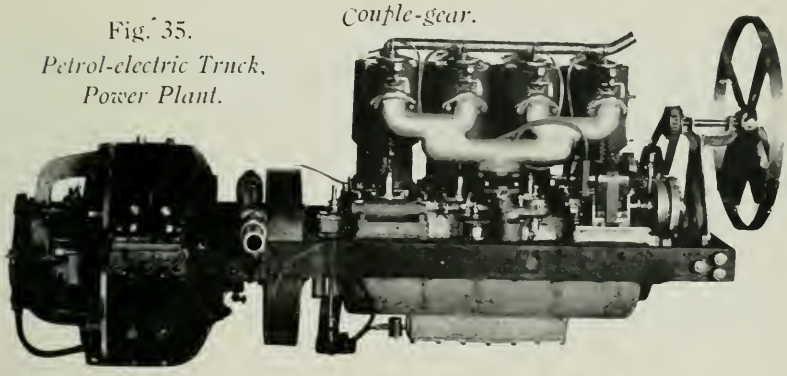


Fig. 36.
Petrol-electric ; Fire-escape.

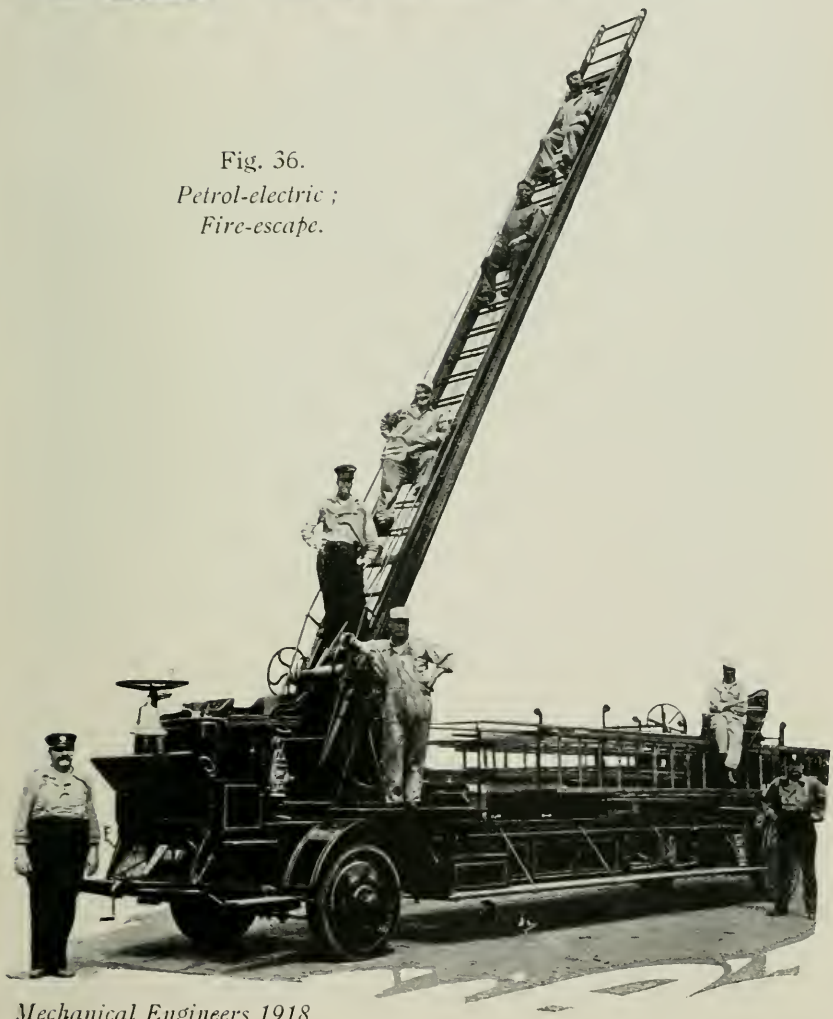


Fig. 43. *Chain-track of Log-Hauler (Phœnix).*

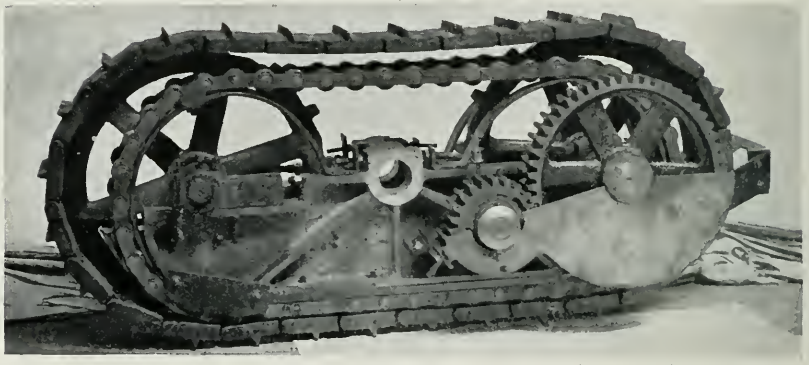


Fig. 44. *Track detail ; Modern Pedrail (Diplock).*

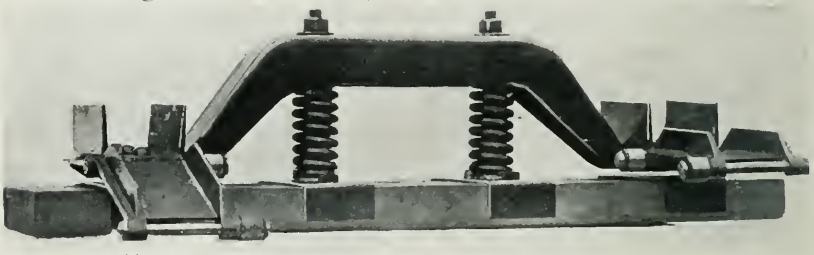


Fig. 55. *Rocker-pin of Tracklayer (Best).*

Fig. 56. *Track-shoe ; Pressed-steel.*

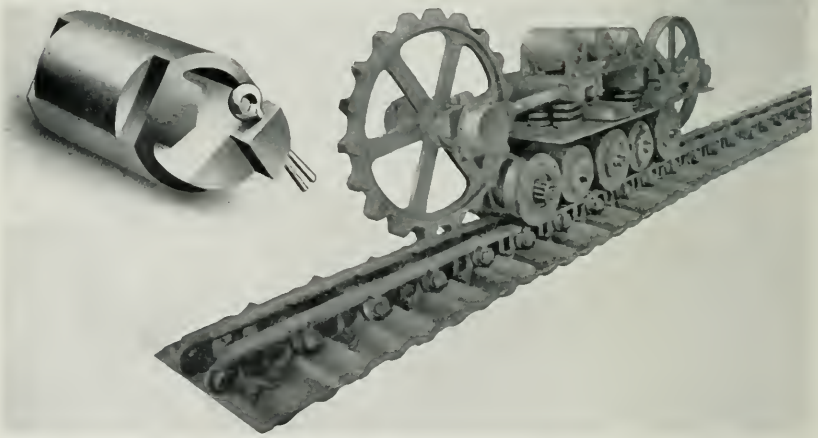
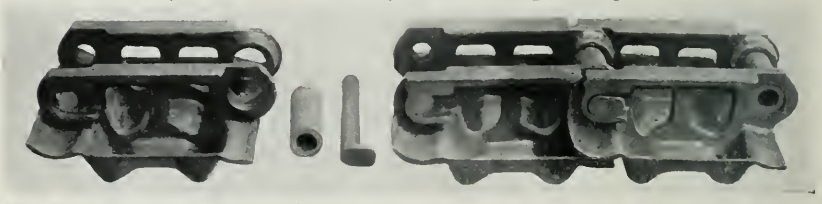


Fig. 57. *Track-shoe of Steel-casting ; one-piece.*



Log-Hauler.

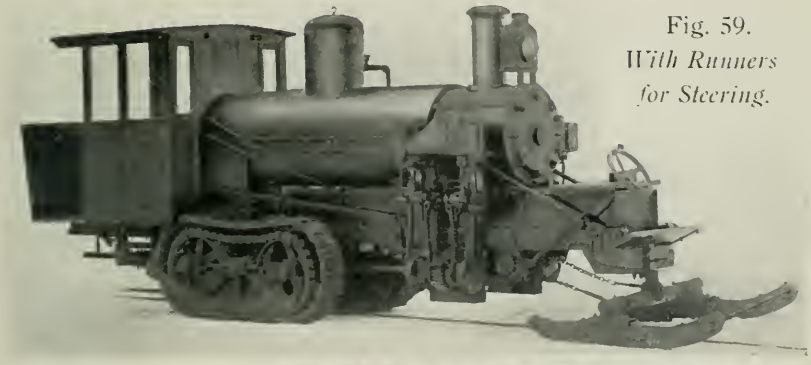


Fig. 59. *With Runners for Steering.*

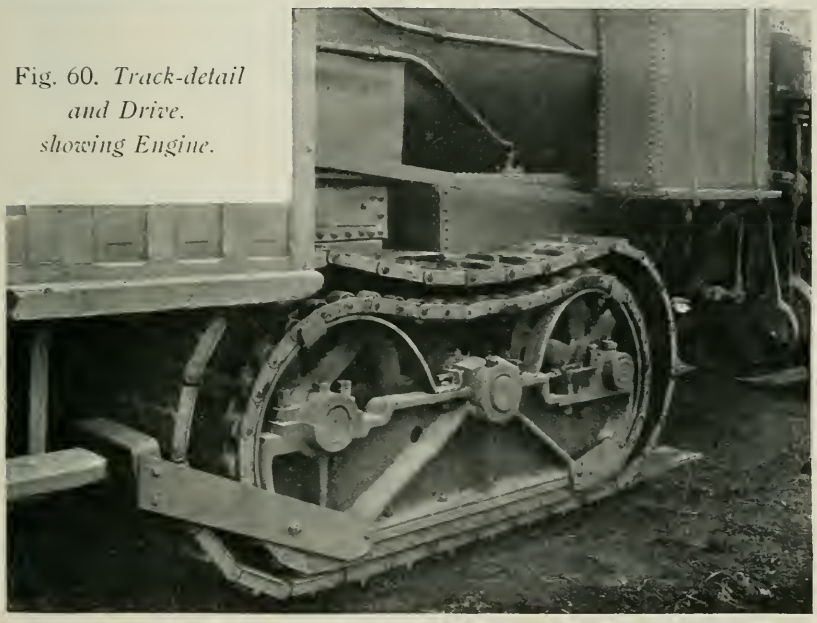


Fig. 60. *Track-detail and Drive. showing Engine.*

Fig. 61. *Showing small Ground-clearance for Snow.*

Mechanical Engineers 1918.

Log-Hauler.

Fig. 62. *Showing relative width of Engine and Sleigh-tracks.*

Fig. 63. *With Load of Sawn Timber.*

Fig. 64. *View of 420-ton Train of Logs.*

Fig. 65. *Log-Hauler ; on Curve.*

Fig. 66. *Centiped Truck.*

Fig. 67. *Centiped : Hauling Wagons on Soft Sand.*

Mechanical Engineers 1918.

Centiped.

Fig. 68.
Crossing Ditch.

Fig. 69.
Crossing Railway Track.

Fig. 70. *Detail of Track.*

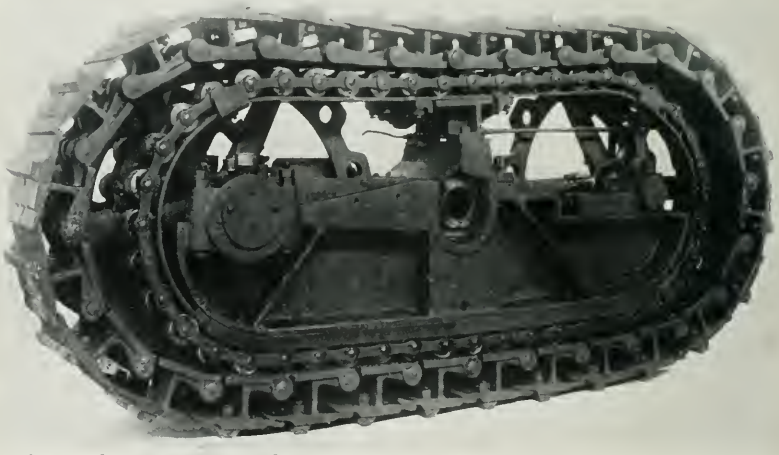
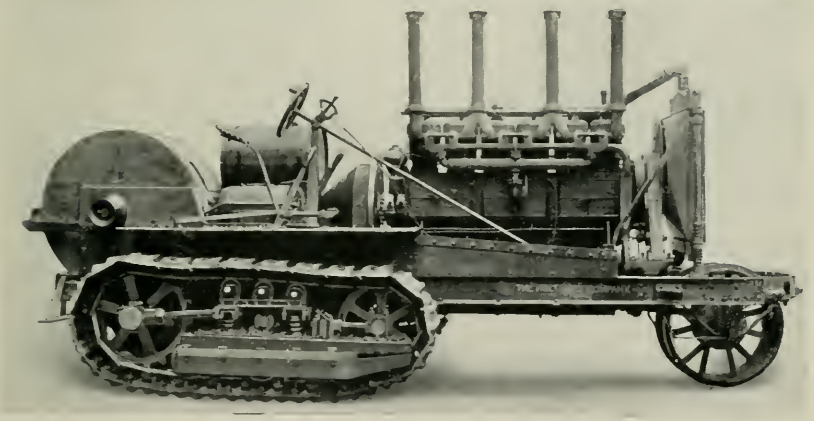


Fig. 71. *Centiped ; Ploughing 30-inch Furrow.*

Fig. 72. *Centiped ; Road-grading.*

Fig. 74. *Caterpillar ; 120 h.p.*



Mechanical Engineers 1918.

Caterpillar.

Fig. 75. *75 h.p.*

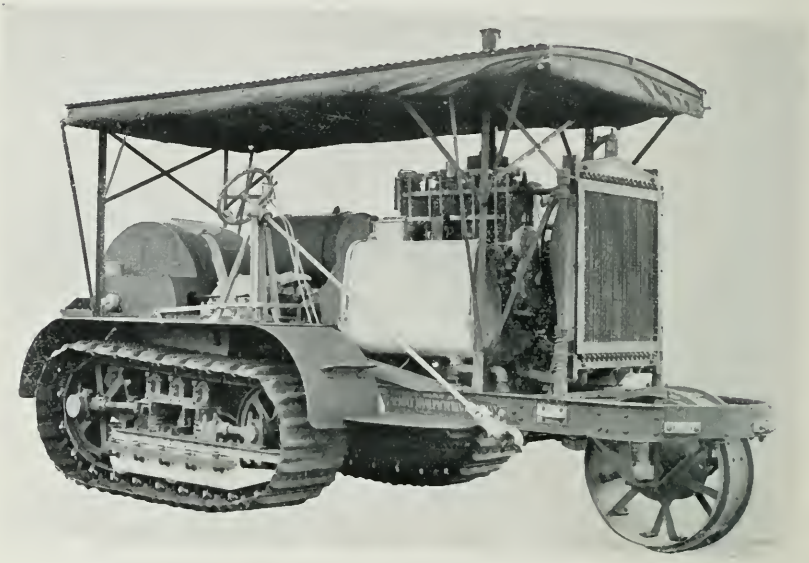
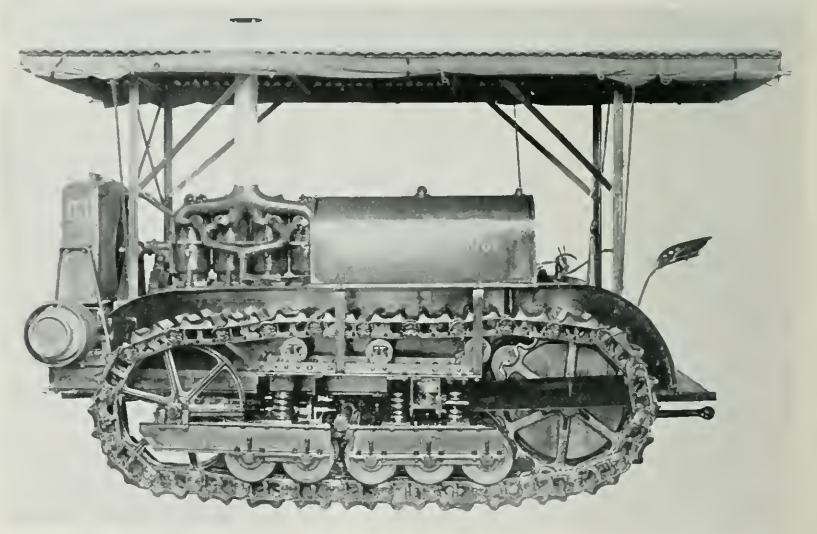


Fig. 76. *45 h.p.*



Caterpillar.

Fig. 77. *45 h.p., Truck Assembly.*

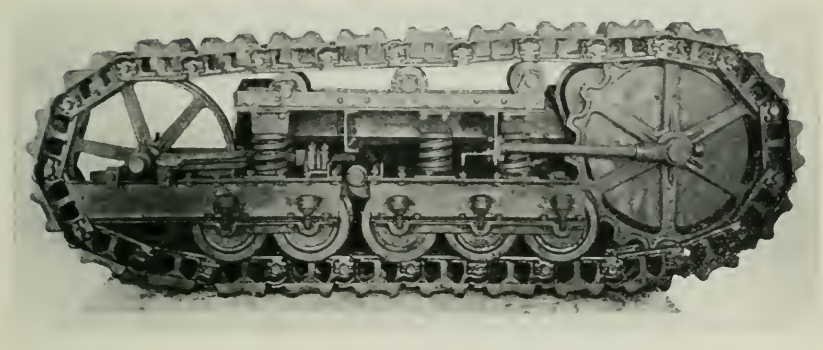


Fig . 78. *18 h.p., with Track laid out.*

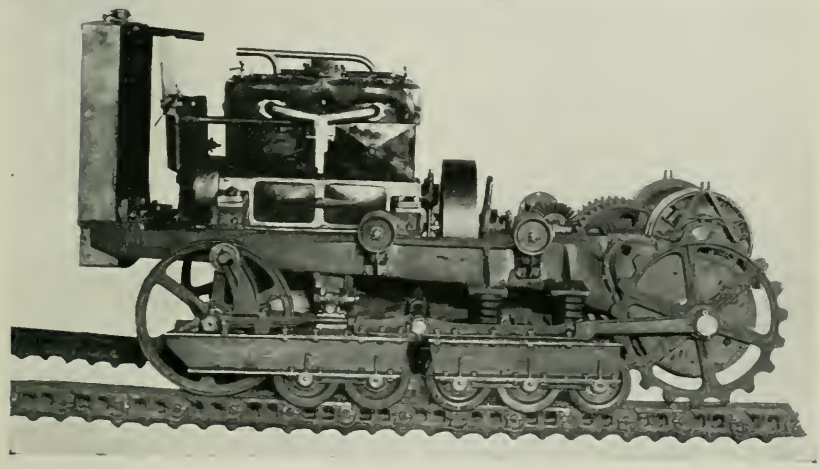


Fig. 79. *18 h.p., view from above.*

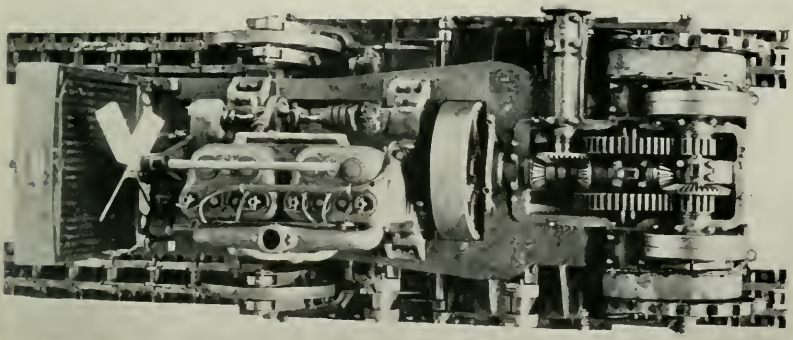


Plate 16. **TRACTION ON BAD ROADS OR LAND.**

Caterpillar.

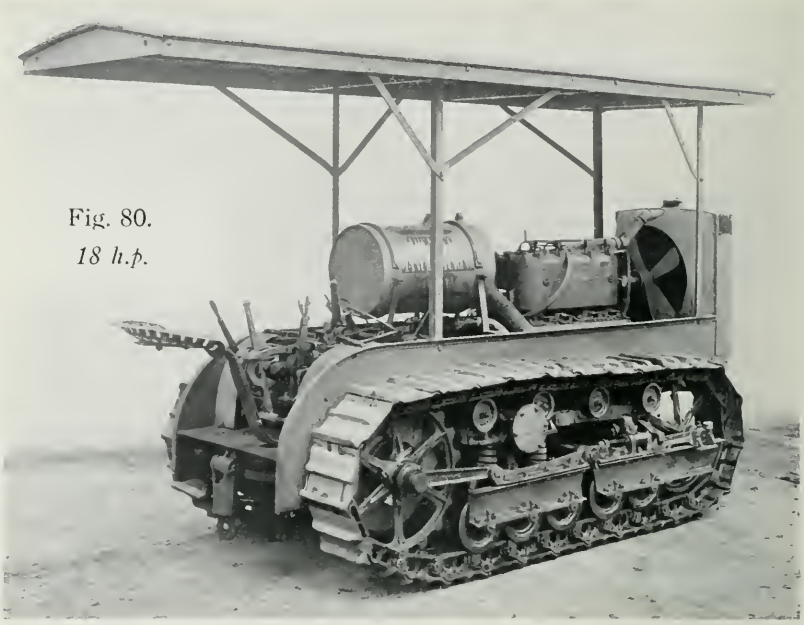


Fig. 80.
18 h.p.

Fig 81. *Cultivating and Harrowing.*

Fig. 82. *Hauling Ditcher.*

Mechanical Engineers 1918.

Caterpillar.

Fig. 83. *Working for White Pass and Yukon Railroad.*

Fig. 84. *Hauling Logs on Sleigh.*

Fig. 85. *Clearing Snow at Butte, Montana.*

Clayton.

Fig. 92. *110 h.p. Tractor.*

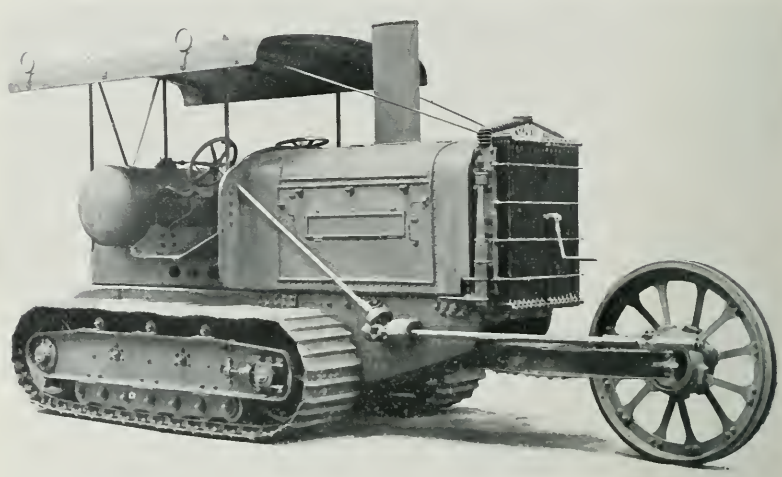
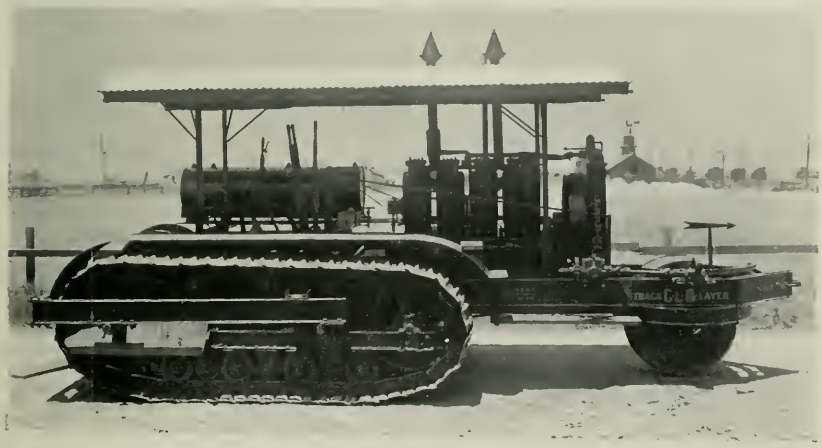


Fig. 93. *110 h.p. Tractor ; Hauling Test Load.*

Fig. 94. *Clayton 110 h.p. Tractor ; on 40° Gradient ; front wheel off the ground.*

Fig. 101. *Tracklayer ; 90 h.p.*



Mechanical Engineers 1918.

Plate 20. **TRACTION ON BAD ROADS OR LAND.**

Tracklayer.

Fig. 102.
30-h.p.

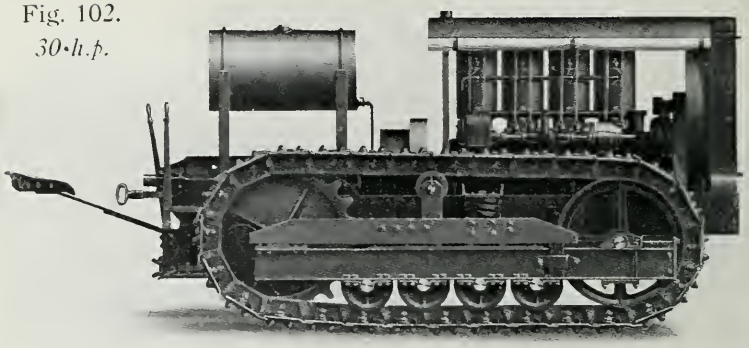


Fig. 103. *Detail of Differential and Drive-sprockets.*

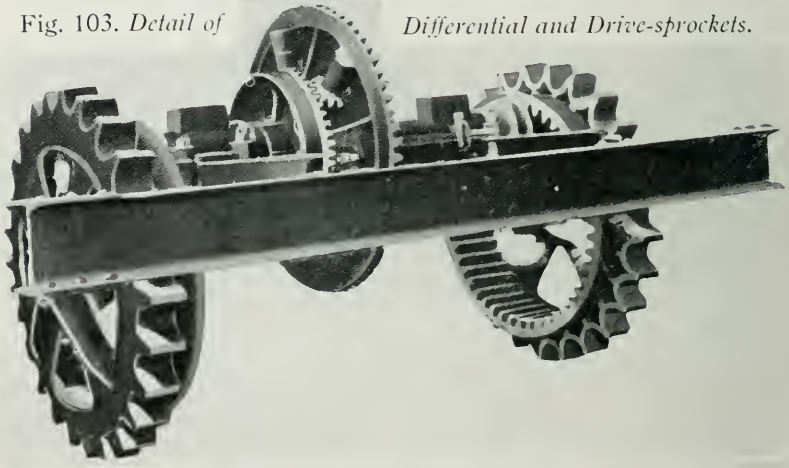


Fig. 104.
Ploughing in Reeds, California.

Mechanical Engineers 1918.

Creeping-Grip.

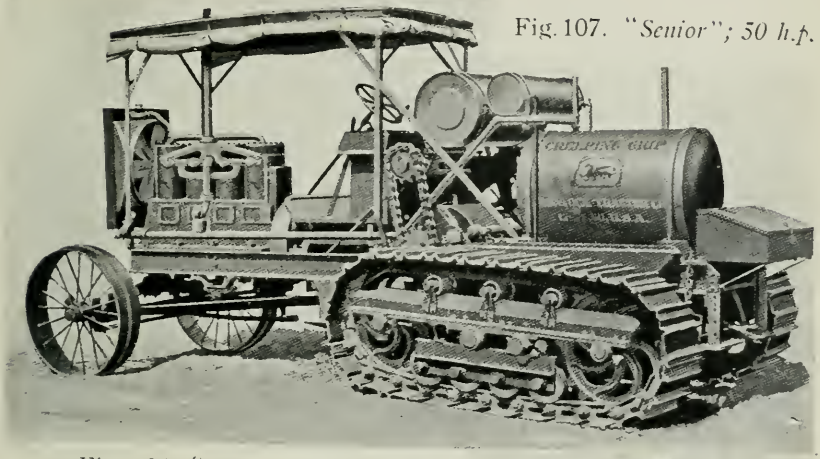


Fig. 107. "*Senior*"; *50 h.p.*

Fig. 108. "*Baby*"; *16 h.p.*

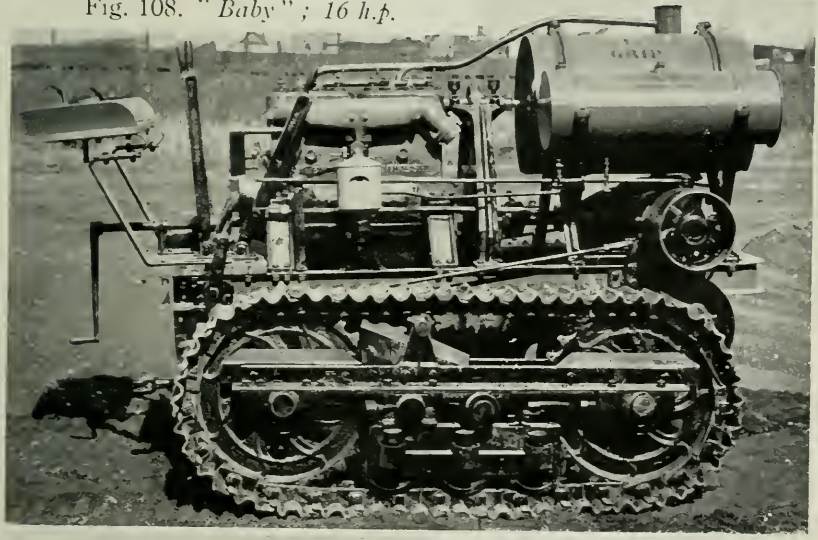


Fig. 109. "*Baby*"; *16 h.p., Cultivating.*

Fig. 110. *Creeping-Grip ; Truck.*

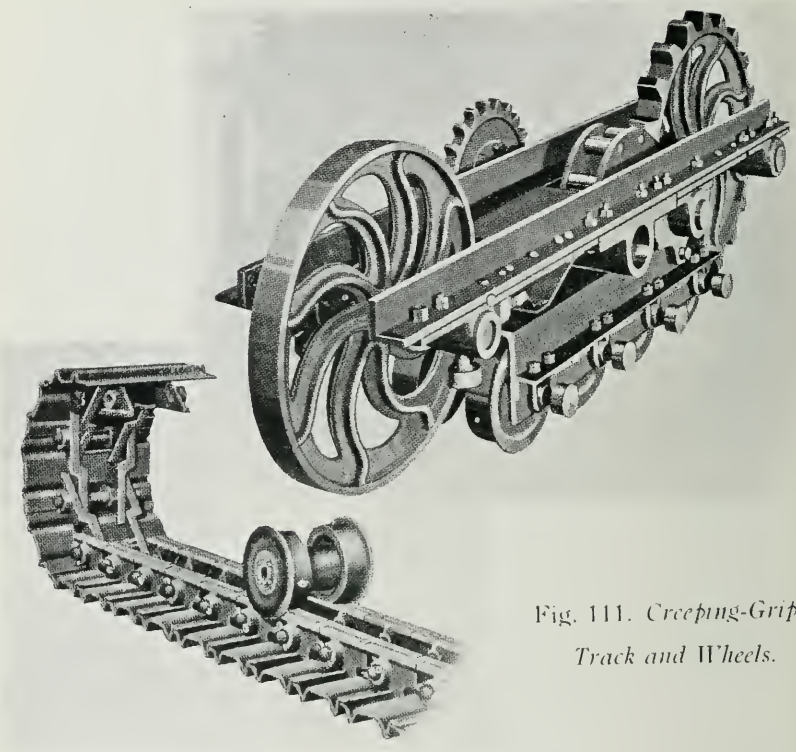


Fig. 111. *Creeping-Grip ; Track and Wheels.*

Fig. 112. *Austin Tractor ; 35 h.p.*

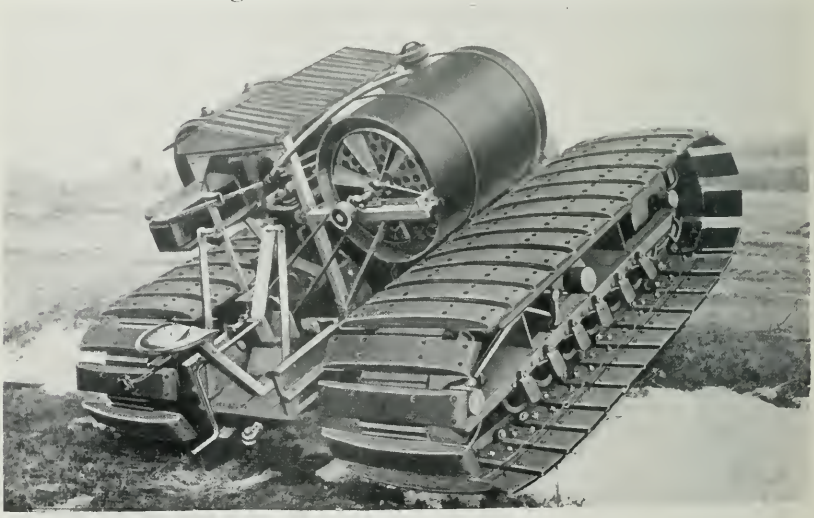


Fig. 113. *Austin Tractor; 15 h.p.*

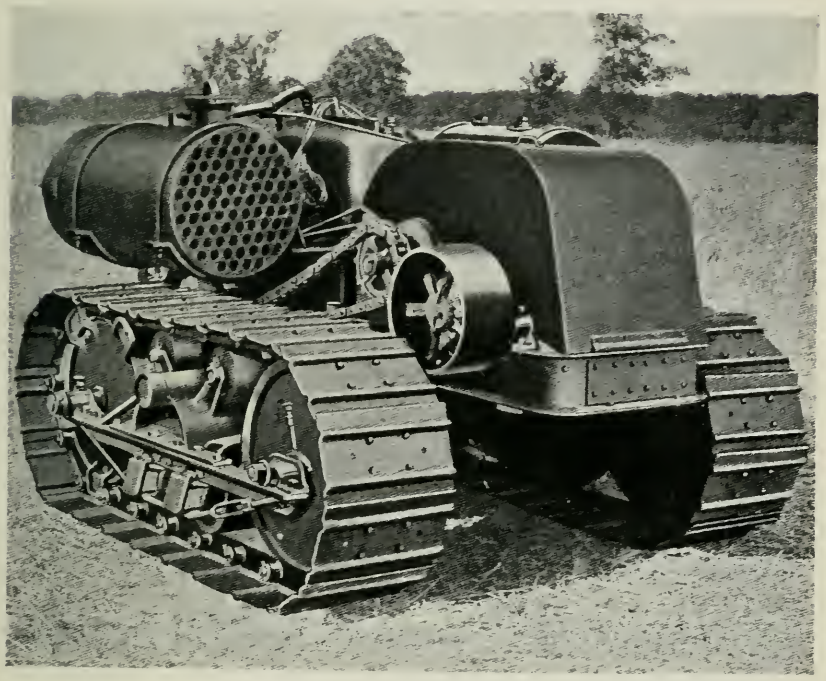
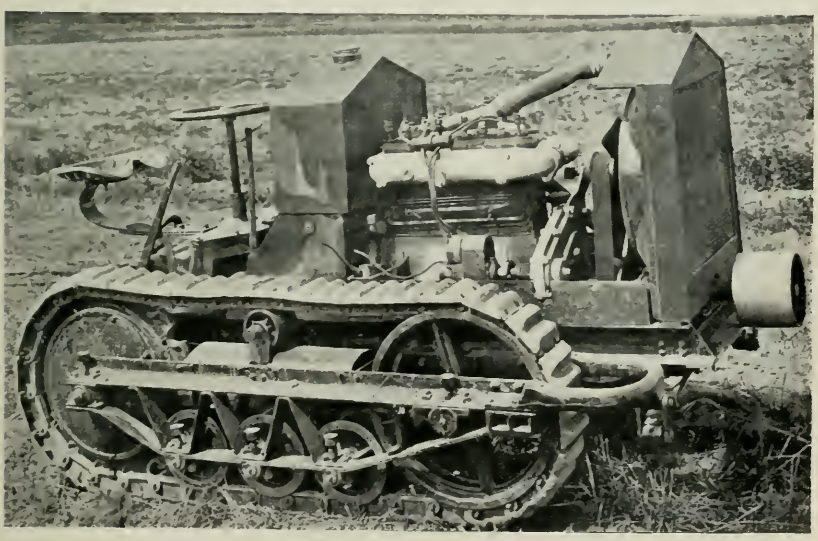


Fig. 114. *Burford-Cleveland Tractor.*



Mechanical Engineers 1918.

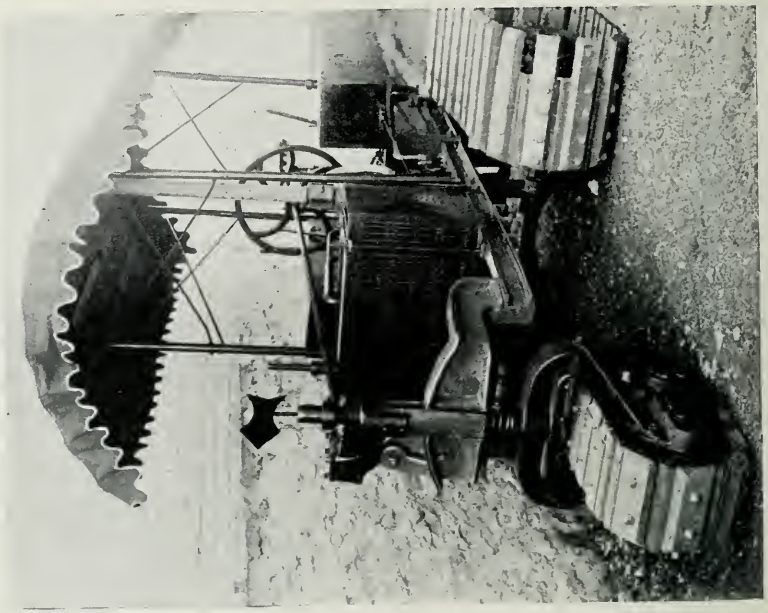


Fig. 116. *Strait Tractor; Front view, showing Steering-track.*

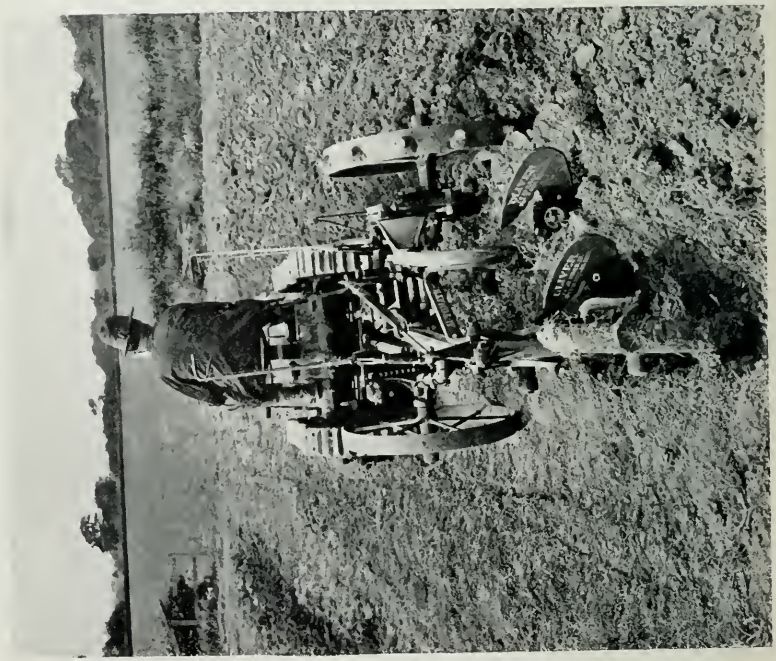


Fig. 115. *Burford-Cleveland Tractor. Hauling Ploughs.*

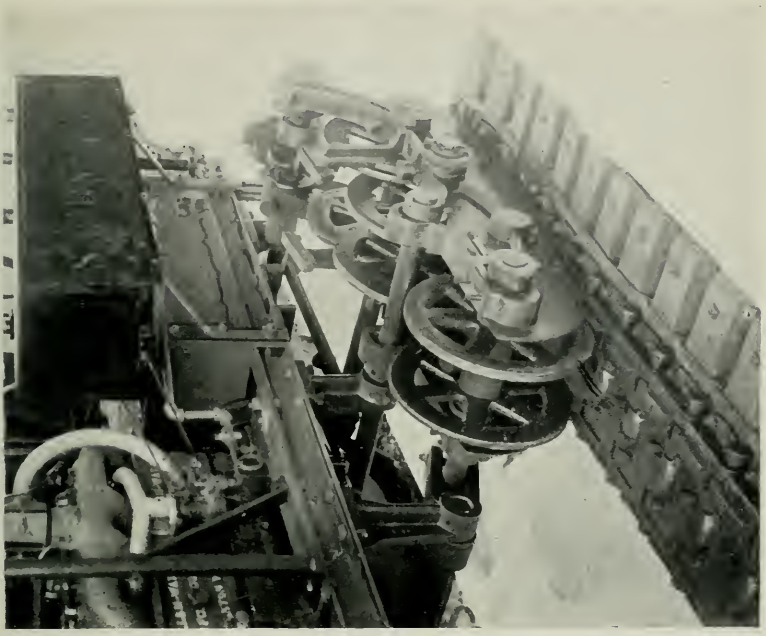


Fig. 118. *Detail of Track-frame.*

Strait Tractor.

Fig. 117. *Model 3, Single-track Tractor; Deep Ploughing.*

Plate 26. **TRACTION ON BAD ROADS OR LAND.**

Strait Tractor.

Fig. 119. *Side view.*

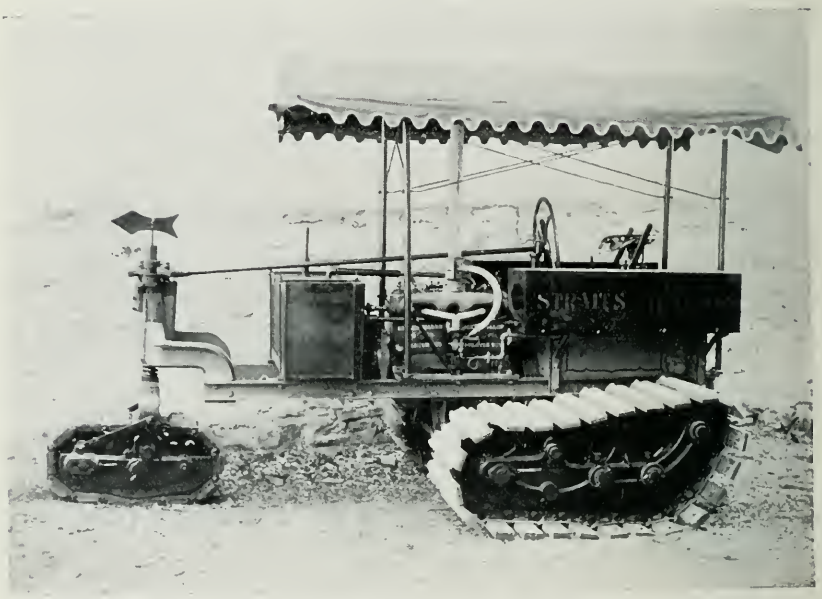


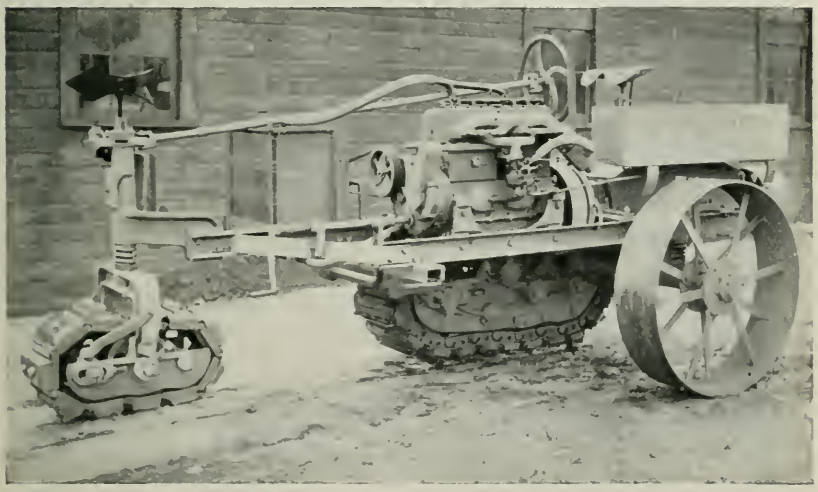
Fig. 120. *Hauling a House on a dirt road.*

Mechanical Engineers 1918.

Strait Tractor.

Fig. 121. *Ploughing in old sod.*

Fig. 122. *Model 3 ; Side view.*



Mechanical Engineers 1918.

Plate 28. **TRACTION ON BAD ROADS OR LAND.**

Yuba Tractor.

Fig. 124. *Side view.*

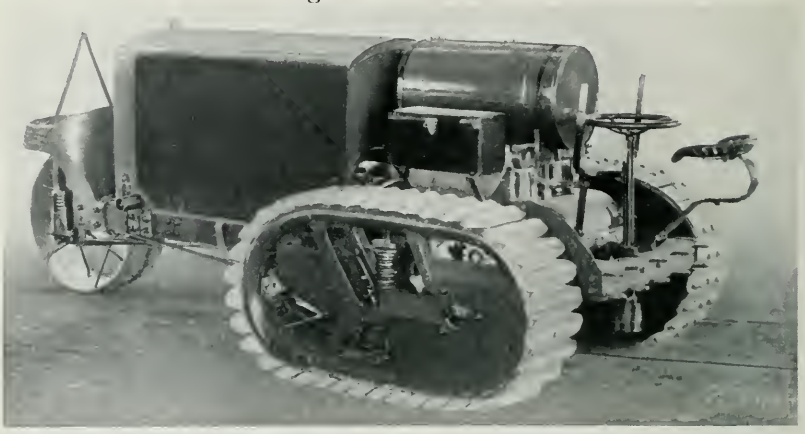


Fig. 125. *Detail of Truck.*

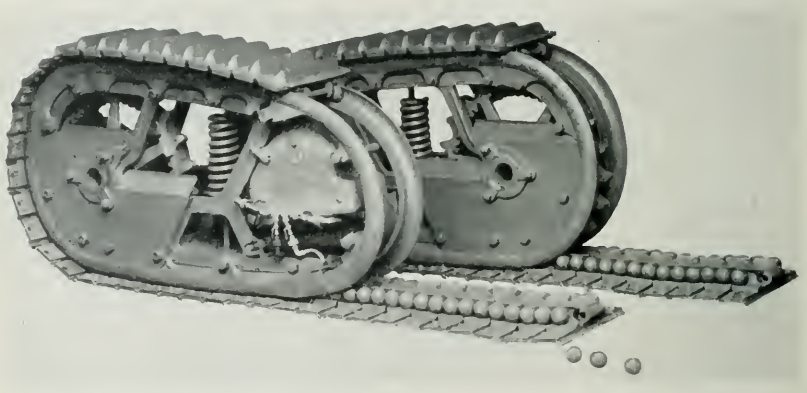
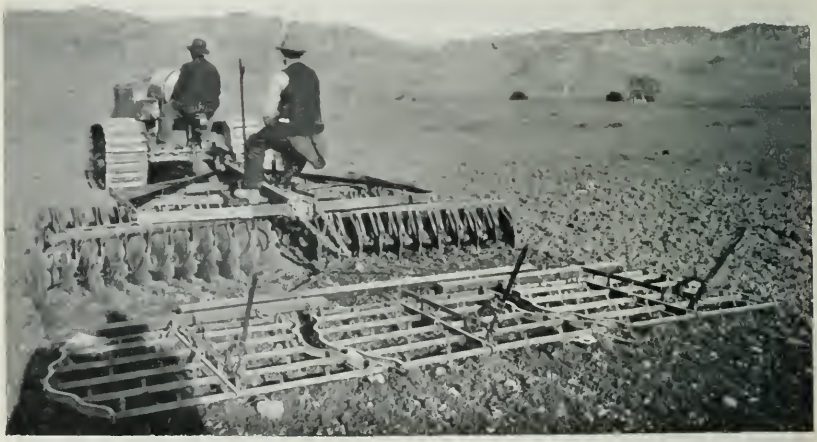


Fig. 126. *Disking and Harrowing.*



Yuba Tractor.

Fig. 127. *Section of Track.*

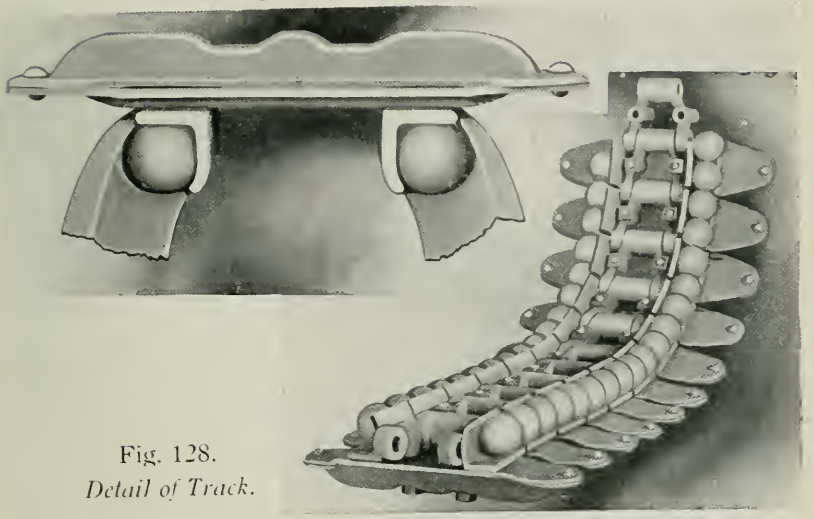
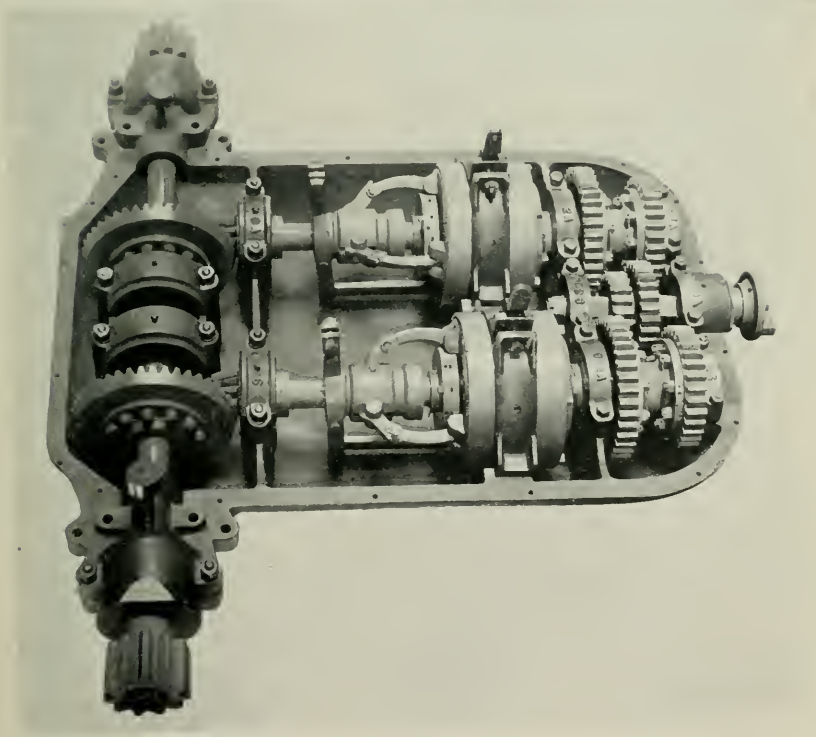


Fig. 128.
Detail of Track.

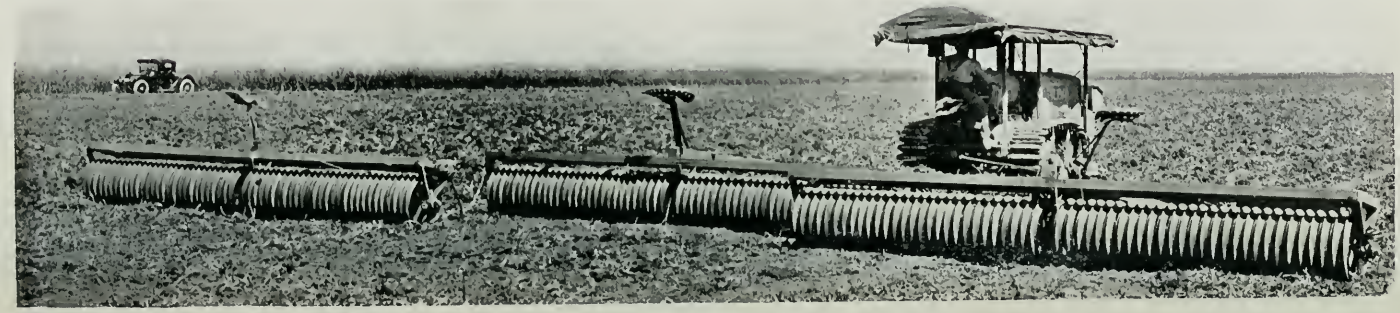
Fig. 129. *Detail of Gear-box.*



Mechanical Engineers 1918.

Yuba Tractor.
Fig. 130. *Hauling Harvester.*

Fig. 131. *Hauling 40 ft. Corrugated Roller in Bean-land.*



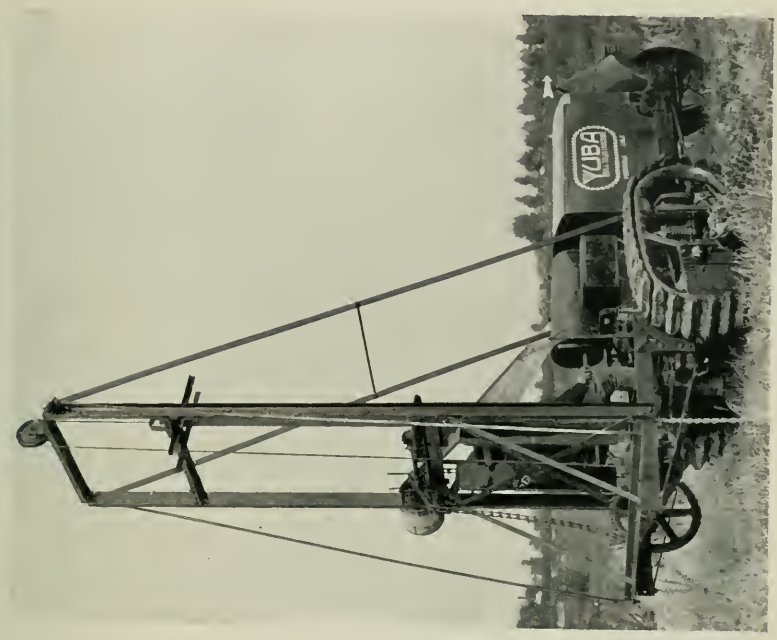


Fig. 133. *Fitted with Hard-pan Driller.*

Fig. 132. *Climbing a 65 per cent gradient.*

Yuba Tractor.

Plate 32. **TRACTION ON BAD ROADS OR LAND.**

Yuba Tractor.

Fig. 134. *On Side-lying ground in Orchard.*

Fig. 135. *Climbing out of Irrigation Ditch.*

Fig. 136. *Harvesting Rice.*

Mechanical Engineers 1918.

Martin Cultivator.

Fig. 137. *Two-Plough.*

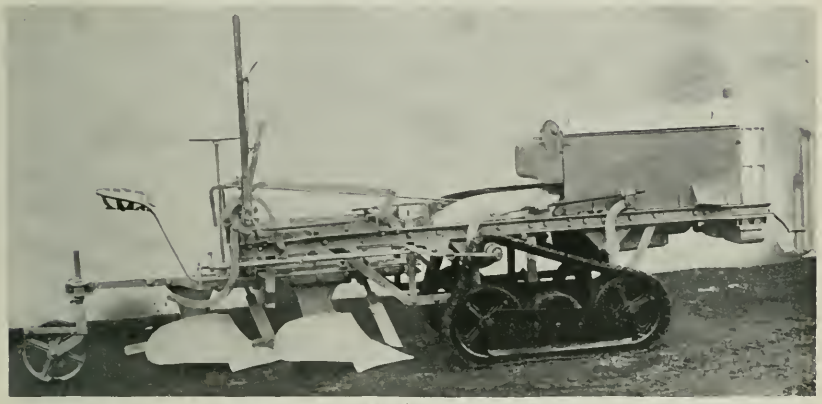


Fig. 138. *With Steering Wheels.*

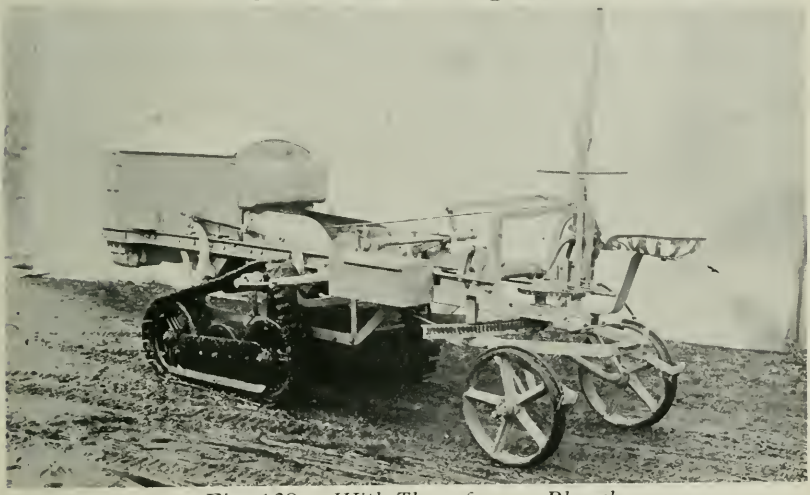


Fig. 139. *With Three-furrow Plough.*

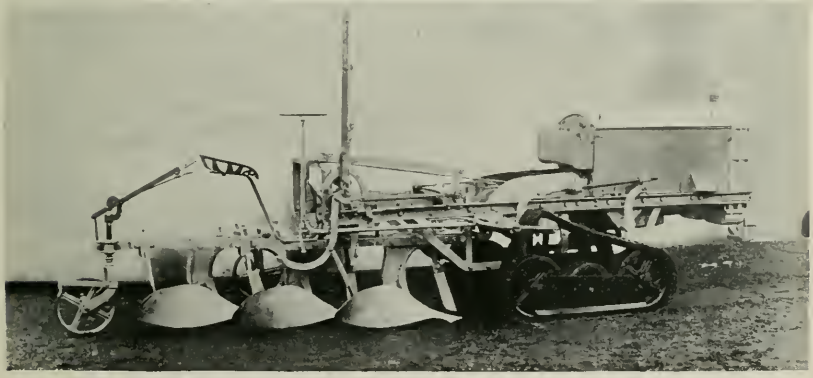


Plate 34. **TRACTION ON BAD ROADS OR LAND.**

Fig. 140. *Martin Cultivator ; Ploughing.*

Fig. 141. *Martin Cultivator ; Hauling.*

Fig. 143. *Scott Motor-Sleigh ; on ground.*

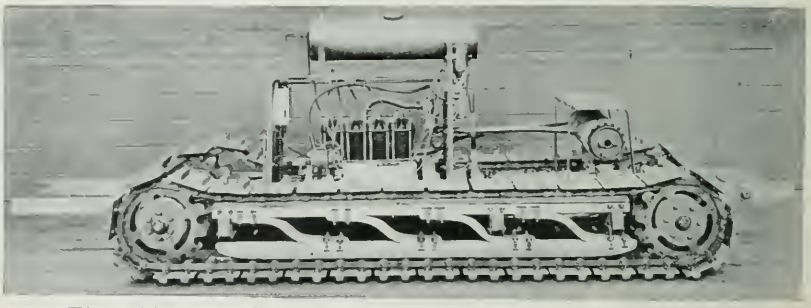


Fig. 144. *Scott Motor-Sleigh ; on Blocks showing Chain Sag.*

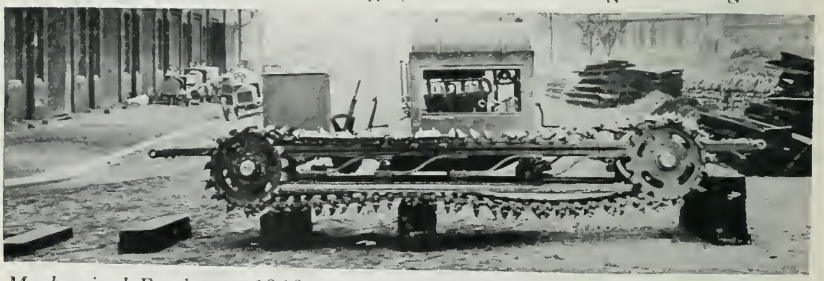


Fig. 145. *Scott Motor-Sleigh ; climbing a slope.*

Fig. 146. *Scott Motor-Sleigh ; Test on Lake Fefor, Norway.*

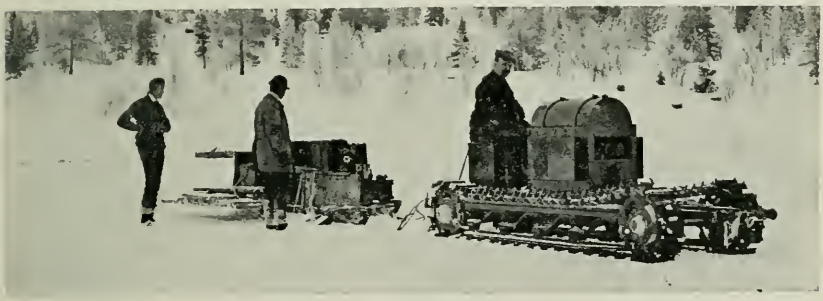
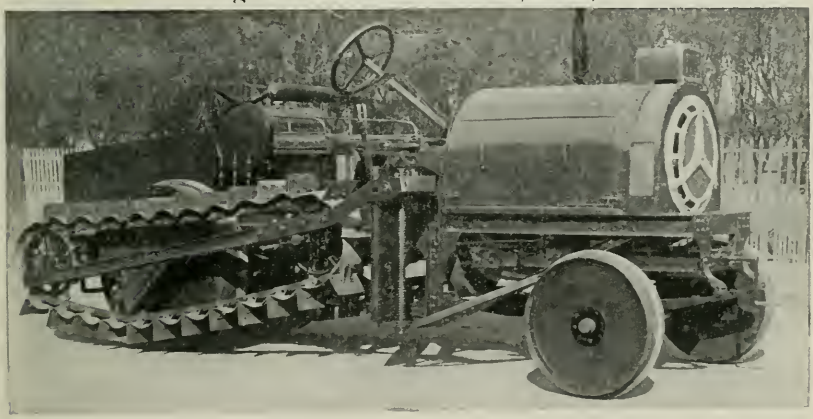


Fig. 147. *Lefebvre Tractor ; 45 h.p.*



Mechanical Engineers 1918.

Fig. 148. *Caterpillar with Train of Chain-track Haulage Wagons.*

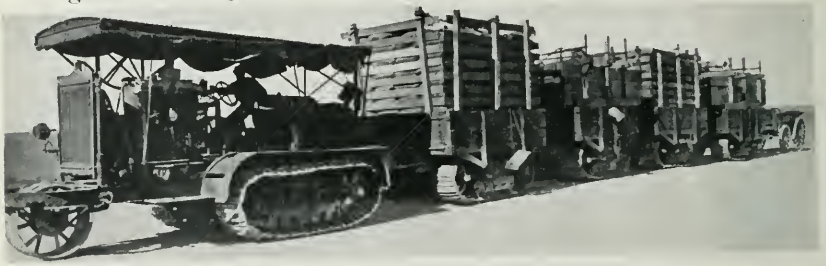


Fig. 149. *Caterpillar with Chain-track Haulage Wagons.*

Fig. 150. *Pedrail Haulage Wagon.*

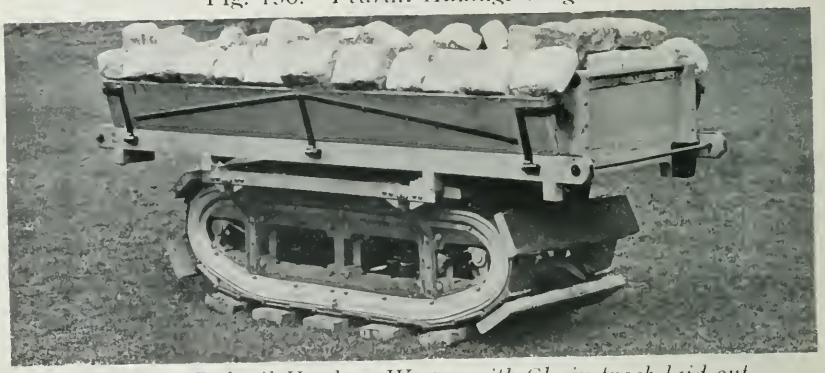


Fig. 151. *Pedrail Haulage Wagon with Chain-track laid out.*

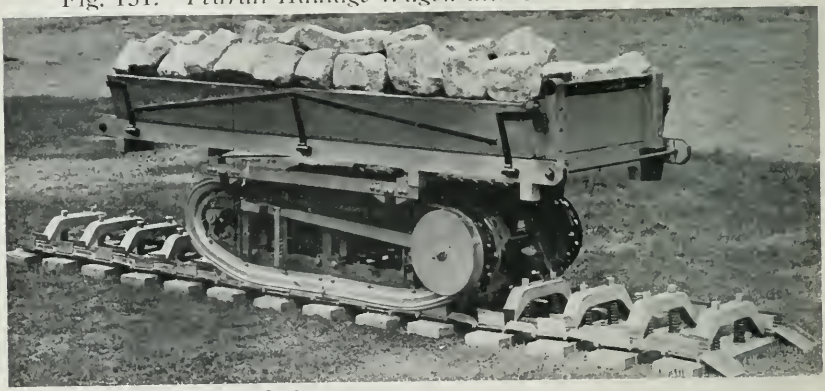


Fig. 152. *Parsons' Model 60 Ditcher ; Side view.*

Fig. 153. *Parsons' Model 48 Ditcher ; Front view.*

Mechanical Engineers 1918.

Fig. 154. *Parsons' Model 24 Ditcher ; Back view.*

Fig. 155. *Austin Ditcher ; Digging 10 feet deep, 27 inches wide.*

Fig. 156. *Austin Ditcher with Bank-sloping Device ; Digging 5 ft. deep, 3 ft. bottom, 1 to 1 slope.*

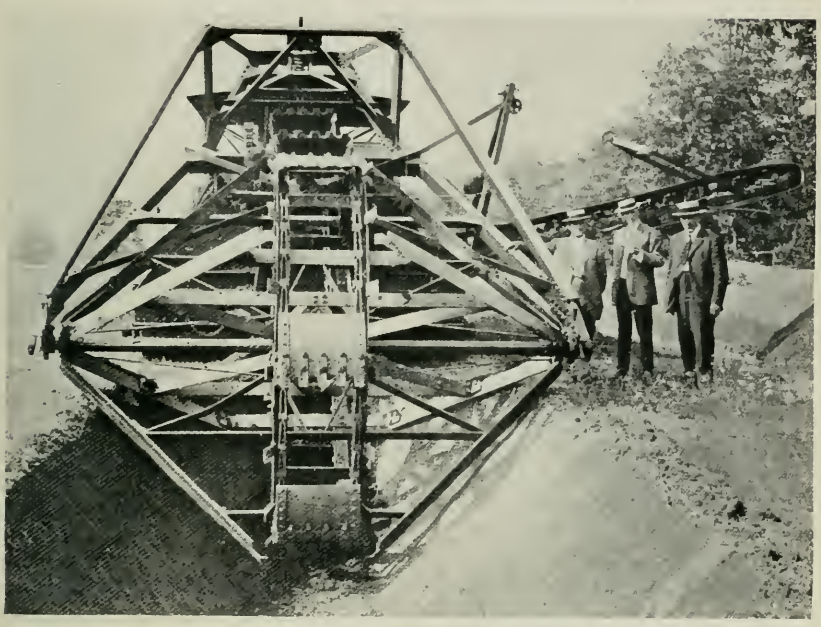
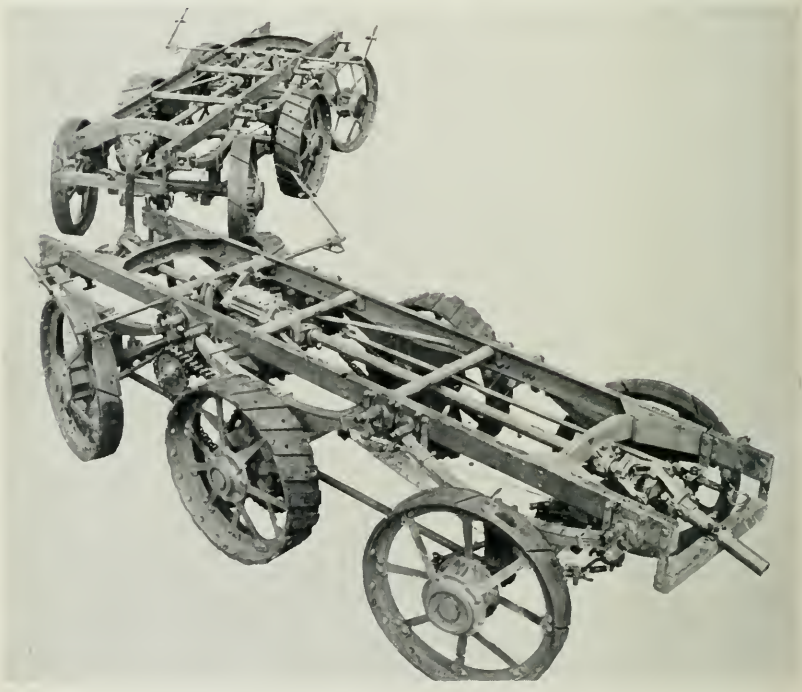


Fig. 157. *Parsons' Back Filler.*

Mechanical Engineers 1918.

Fig 158. *Renard Road Train,*
with 20-ton load crossing swampy field.

Fig. 159. *Renard Road Train ; Chassis connected.*



Mechanical Engineers 1918.

TJ
1
I4
1918
v.1

Institution of Mechanical Engineers, London
Proceedings

Plumbe Applied Sci... Scienb...

Engineering

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY

ENGIN STORAGE